TASK 3

PRE-PROJECT EVALUATION REPORT

KNIGHTS FERRY GRAVEL

REPLENISHMENT PROJECT

Work Authority #1469-8520, Project #97-N21

Produced for

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EXECUTIVE SUMMARY

Study objectives were to document pre-project spawning habitat conditions at 18 project sites, seven control sites, and a California Department of Fish and Game restoration site in upper Goodwin Canyon for the Knights Ferry Gravel Replenishment Project, CALFED Project #97-N21. Due to high streamflow releases in fall 1998, it was necessary to divide the work into two phases: the first during fall 1998 and the second during August 1999. During the first phase, salmon spawner use was monitored at eight- to 10-day intervals from 30 October to 13 December 1998, streambed elevations were measured at a single transect at each riffle, and intragravel dissolved oxygen levels and the vertical hydraulic gradient (VHG) were measured at 81 standpipe sites. During the second phase, streambed elevations were mapped with a total station, and gravel permeability, dissolved oxygen, VHG and substrate bulk samples were collected at 123 standpipe sites within the 25 KFGRP riffles.

Escapement and redd densities were relatively high in fall 1998 compared to escapements since 1988. Redd densities where the gravel had not been mined were negatively correlated with distance below Goodwin Dam. Very few redds were observed in the most downstream riffle, which is about 18 miles below Goodwin Dam. There are no statistically significant differences between the control sites and the unmined sites within the project riffles. However, redd densities within the mined areas of the project riffles were consistently low regardless of location.

Substrate permeability and intragravel dissolved oxygen concentrations were low and the percentage of substrate particles smaller than 1 mm was high at many of the 77 standpipe sites measured in fall 1998 and 123 sites measured in August 1999. In August 1999, permeability rates in undisturbed gravel averaged 3,129 cm/hr (range of 0 to 13,359 cm/hr). In fall 1998, the intragravel dissolved oxygen concentrations were below 5 ppm (probably lethal for eggs) at 8% of the standpipe sites, and between 5 and 8 ppm (possibly lethal and stunts embryo growth) at 9% of the sites. Ten of the 25 riffles had sites where dissolved oxygen was less than 8 ppm. The median diameter for most of the 50 surface bulk samples collected in August 1999 was within the range that chinook salmon can move during redd construction. The percent finer than 6.35 mm for the surface substrate bulk samples was within the range that is suitable for fry emergence at most of the study sites. However, the percentage of particles finer than 1 mm in the subsurface layer averaged 11.3% and ranged from 0.23% to 35.8%. The VHG was typically positive and averaged 0.113 in fall 1998 indicating that upwelling occurred at most standpipe sites except for a few where the streambed was flat. In August 1999, VHG measurements were negative, indicating that downwelling was occurring at most of the sites where the gradient ranged from 0 to 14%. The $adj\text{-}R^2$ for linear regressions between dissolved oxygen, the natural log of permeability, the percentage of substrate particles finer than 1 mm in the subsurface sample, VHG, streambed gradient, and distance below Goodwin Dam were never more than 0.317 for the fall 1998 and August 1999 data sets.

The density of redds in a 20-foot radius about the standpipes is negatively correlated with the distance below Goodwin Dam and the percentage of substrate particles finer than 1 mm in the subsurface sample and positively correlated with the dissolved oxygen concentration measured in fall 1998. Redd densities were highest at standpipe locations where the streambed gradient ranged between 0 and 5% as occurs in flat areas and moderately sloped pool tails. There is no

significant correlation with gradient because the relationship was not linear. There is a weak positive correlation between redd density and VHG measured in summer 1999, which is assumed to be false, since there is no correlation with VHG measured in fall 1998 when the salmon were spawning. There are no correlations between redd density and substrate permeability.

The monitoring conducted in fall 1998 and August 1999 should be adequate to document the pre-project conditions at the 25 riffles studied and test the hypotheses regarding the relations between spawning habitat restoration and salmon use, expected egg survival to emergence, and useful life of the restoration riffles. The contour maps produced with a total station provide the exact location of the salmon redds relative to where gravel was placed in fall 1999. A casual inspection of the project riffles in July 2000 suggests that restoration gravel moves short distances in an amoeba-like fashion and so total station measurements should be adequate to document the transport of restoration gravel in the Stanislaus River. In addition, the pre-project measurements of intragravel dissolved oxygen, permeability, substrate composition, and VHG should be adequate to determine the useful life of the restoration riffles.

It was not possible to investigate the suitability of riffle habitat for incubating eggs in fall 1998 because flows were too high to install monitoring equipment. Conditions for incubating eggs were monitored in fall 1996 and fall 1999 under post-project conditions by constructing artificial redds with buried minipiezometers and thermographs. A study of the relation between intragravel water temperatures, apparent velocity, permeability, and dissolved oxygen within the artificial redds will be made in fall 2000.

Monitoring at one of the Department of Fish and Game restoration sites in upper Goodwin Canyon indicated that redd densities there were about three times higher than those at nearby KFGRP riffles. In addition, intragravel dissolved oxygen concentrations averaged 99% of saturation levels and upwelling flows were relatively strong within the riffle. Since there was little gravel at the site prior to gravel introduction in 1997, the high redd densities and dissolved oxygen levels indicate that the restoration was initially successful.

INTRODUCTION

This report presents the results of the pre-project spawning habitat studies in the lower Stanislaus River in fall 1998 and summer 1999 for the Knights Ferry Gravel Replenishment Project (KFGRP). The study objectives were to document pre-project conditions for spawning and incubation habitat for fall-run chinook salmon (*Oncorhynchus tshawytscha*) at 18 project sites where a total of 13,000 tons of gravel were added between 4 August and 24 September 1999, seven control sites, and a California Department of Fish and Game (DFG) project site where gravel was added in 1997 in the upper Goodwin Canyon. The study sites occur between the DFG upper Goodwin Canyon site (RM 58) and Oakdale (RM40, Figure 1).

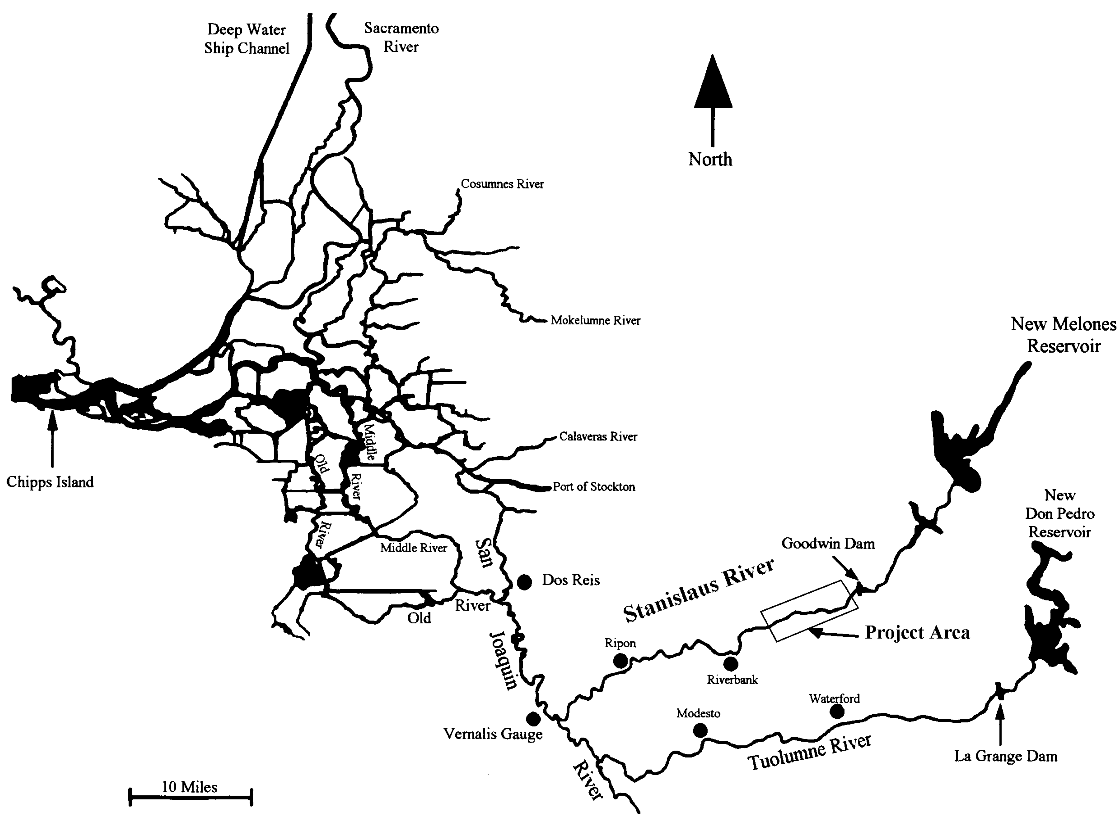

Figure 1. Map of the Sacramento-San Joaquin Delta showing the Stanislaus River, Goodwin Dam, and the project area.

Justification for the KFGRP was based on several studies. A Department of Water Resources (DWR 1994) study of 22 riffles between Goodwin Dam and Riverbank indicated that 45% of the riffles sampled has excessive levels of fines in substrate samples collected from the upper sections of the riffles where the salmon prefer to spawn. Redd surveys in 1994 and 1995 (Mesick 2001a) indicate that most chinook salmon spawned in the 12-mile reach between Goodwin Dam and the Orange Blossom Bridge (RM 46.9). These surveys also indicate that 73% of the salmon spawned upstream of the riffles' crests where the streambed sloped upwards (e.g., tail of a pool). At 12 riffles between Two-Mile Bar (RM 56.6) and Oakdale where redd densities were relatively high in 1994 and 1995, incubation conditions were judged to be suboptimal from November 1995 to February 1996 due to excessive fines, low dissolved oxygen (D.O.) levels, decaying Asian clams (*Corbicula fuminea*) that were buried during redd construction, and the inflow of oxygen-poor groundwater, particularly after intensive rain storms (Mesick 2001a). Substrate samples collected from the upper six inches of the streambed at the 12 study riffles indicated that predicted survival probabilities for chinook salmon eggs using Tappel and Bjornn's (1983) laboratory study averaged 75.6% in the reach above the Orange Blossom Bridge, 58.6% in the lower spawning reach downstream of the bridge to Riverbank, and 95.4% at two restoration sites near the U.S. Army Corps of Engineer's Horseshoe Road park where gravel was added in 1994 (Mesick 2001a). At four natural riffles with pronounced crests, the predicted survival probabilities for chinook salmon eggs based on the percent fines averaged 73.2% at sites upstream of the riffles' crests and 62.1% at sites downstream of the riffles' crests. At the 12 study riffles, intragravel D.O. levels were less than 5 ppm, which can be lethal for chinook salmon eggs (Chapman 1988), at 19% of the piezometers in artificial redds and less than 8 ppm, which reduces embryo growth (Chapman 1988), at 34% of the piezometer sites during five surveys in November and December 1995. Immediately after five intensive rain storms in early February 1996, D.O. levels declined to less than 5 ppm at 34% of the sites and to less than 8 ppm at 50% of the sites. Elevated intragravel water temperatures, an indicator of groundwater inflow, occurred at many of the sites where D.O. levels declined after the intensive rain storms.

The poor quality of spawning habitat in the Stanislaus River has resulted from the blockage of coarse sediment supply from the upper watershed by dams and from instream gravel mining downstream of Goodwin Dam from 1930 to the 1970s (Mesick 2001b). The loss of upstream gravel recruitment has contributed to the armoring of riffles in Goodwin Canyon and the one-mile section immediately downstream of the Knights Ferry County Bridge. Downstream from there, many riffles were completely excavated by in-river gravel mining. Surveys conducted by DFG (1972) in the 1960s suggest that about 55% of the channel between the Knights Ferry County Bridge and the Orange Blossom Bridge was repeatedly mined. Furthermore, a comparison between the 1960s surveys and the surveys in 1995 and 1996 (Mesick 2001a) suggest that the few riffles that were left untouched in the dredged reaches have since become armored and shortened (Mesick 2001b).

Escapement of fall-run chinook salmon to the Stanislaus River has declined from an average of 15,000 fish from 1947 to 1954 to an average of 4,700 fish from 1955 to 1989, and to an average of 737 fish from 1990 to 1998 (Mesick 2001b). While it is likely that water development and Delta exports contributed to this decline, the in-river gravel mining between 1930 and the 1970s probably was another contributing factor (Mesick 2001b). The stock-recruitment relationship for the Stanislaus River chinook salmon population from 1948 to 1995 suggests that recruitment initially increases as stock increases until stock reaches about 2,500 fish and then declines after stock exceeds about 12,500 fish (Mesick 2001b). This suggests that the habitat in the Stanislaus River can support the progeny of only 1,250 pairs of adult salmon.

To evaluate whether adding clean gravel to the streambed of the Stanislaus River improves spawning and incubation habitat, studies were designed to test ten hypotheses identified in the KFGRP Ecological Monitoring Plan (CMC 1999). There are two hypotheses on improving spawning habitat:

> Hypothesis I-A: The density of fall-run chinook salmon redds will be higher in unconsolidated gravel in the project riffles than in the cemented gravel in the control riffles.
>
> Hypothesis I-B: The higher the elevation of a riffle's crest, the greater will be the rate of surface water downwelling that presumably helps attract spawners.

There are three hypotheses on improving incubation habitat:

> Hypothesis II-A: Adding gravel without fines to the streambed increases intragravel flow in redds.
>
> Hypothesis II-B: Higher gradients of the streambed upstream of the hydraulic control at the riffle's crest result in higher rates of surface water downwelling that presumably increases intragravel dissolved oxygen concentrations.
>
> Hypothesis II-C: The low percentage of fines in the project riffles will result in high intragravel D.O. concentrations relative to those at the control riffles, where the concentration of fines is high.

Other hypotheses were developed to improve the techniques required to restore spawning habitat. In summer 1994, DFG and DWR reconstructed two riffles, R27 and R28, in the Stanislaus River near the Horseshoe Road Recreation Area (RM 50.4 and RM 50.9) and another riffle just upstream of the Orange Blossom Bridge (RM 47.4). These three riffles were reconstructed by excavating the channel bed to a depth of 1.5 feet to remove gravel and silt, and replacing the excavated material with washed gravel, sized from 0.5 to 4 inches (Kondolf and others 1996). The washed gravel was imported from the Blasingame Quarry near the Merced River and about 60% of the rock had sharp edges (Mesick 2001a). Only about 20% of natural gravel from the Stanislaus River had sharp edges (CMC and others 1996). Rock weirs were constructed at the upstream and downstream boundaries of each site to achieve the "necessary grade" of 0.2% to 0.5% and to retain the imported gravel during high flows. Redd surveys at these two riffles (R27 and R28) at the Horseshoe Road Recreation Area indicated that few salmon spawned in the added gravel through fall 1997, whereas redds were observed in natural gravel adjacent to the added gravel (Mesick 2001a). By fall 1996, at least half of the gravel had been flushed from Riffle R27 and almost all of the gravel had been flushed from Riffle R28. A mature cottonwood tree that had fallen into the middle of Riffle R28 appeared to increase the rate that the gravel was scoured from the site. After a 15-foot-long, two-foot high berm of natural gravel had been deposited across the crest of Riffle R27 in spring 1997, 16 redds were observed in the gravel berm and one redd was observed in the added gravel in fall 1997.

In 1996 and 1997, DFG added about 2,000 tons of gravel obtained near the Stanislaus River to several sites in upper Goodwin Canyon where gravel was scarce. The added gravel, obtained near the Stanislaus River, contained very little angular rock, and ranged from 0.35 to 5 inches in diameter. It was added to the undisturbed streambed in pools and in bars across shallow areas. Many salmon spawned in this new gravel in the first season.

Two categories of hypotheses were developed to test why the salmon utilize some restoration sites but not others. One category includes three hypotheses on the sizes and sources of gravel used for restoration projects:

> Hypothesis III-A: Restoration gravel obtained from near the Stanislaus River will be used by more Stanislaus River chinook salmon than will gravel obtained from another watershed.
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> Hypothesis III-B: Restoration gravel between 3/8 inch and 5 inches will produce higher gravel permeabilities than will gravel between 1/4 inch and 5 inches.
>
> Hypothesis III-C: Restoration gravel between 1/4 inch and 5 inches will attract more spawners than will gravel between 3/8 inch and 5 inches.

The second category includes two hypotheses on the effects of the streambed configuration on the useful life of the project.

> Hypothesis IV-A: During high flows, high-crested riffles retain more gravel than moderate-crested riffles, which retain more gravel than low-crested riffles.
>
> Hypothesis IV-B: Project riffles in mined channels will lose gravel at a faster rate than will project riffles adjacent to functional floodplains.

The purpose of the Task 3 Pre-Project studies is to begin testing these hypotheses by collecting data to be compared with post-project conditions measured in Tasks 5 and 6. Hypotheses testing will begin with Task 5 Post Project studies.

METHODS

Due to high streamflow releases in fall 1998, it was necessary to divide the monitoring work into two phases, one during fall 1998 and the other during summer 1999. During the first phase of work when releases from Goodwin Dam were about 500 cfs, salmon spawner use was monitored at eight- to 10-day intervals from 30 October to 13 December at the 26 study sites between the DFG upper Goodwin Canyon site (DFG2 at RM 58) and the Oakdale site (Riffle R78 at RM 40.2). From 2 to 14 November 1998, streambed elevations were measured at a single transect at each of the 18 KFGRP project riffles. Between 28 November and 6 December 1998, intragravel dissolved oxygen levels and the vertical hydraulic gradient was measured at each of the 26 riffles.

Work in the river was difficult at 500 cfs and the second phase of work, which included streambed surveying, gravel permeability measurements, intragravel dissolved oxygen measurements, and substrate bulk sample collections, was postponed until summer 1999 when base flows were scheduled to be about 300 cfs. However, 50,000 acre-feet of water was purchased to increase flows in summer 1999 to at least 600 cfs through 4 August 1999. Therefore, the second phase of field work was postponed until 2 August 1999, when work began at Riffles TMA, R1, and R43 at flow releases of 600 cfs. Work at the remainder of the sites, which occurred from 5 to 24 August 1999, was conducted at a release of 500 cfs. Due to the high flows, standpipe measurements and substrate bulk samples could not be collected from some locations in the riffles that were deeper than about 4 feet and 3 feet, respectively.

STUDY AREA

The spawning reach for fall-run chinook salmon in the Stanislaus River is about 25.5 miles long and extends from Goodwin Dam, which is impassible for salmon, downstream to the town of Riverbank. During fall 1995 surveys, the riffles in the spawning reach were numbered and their locations marked on USGS quadrangles. In the 4.2 mile high-gradient canyon between Goodwin Dam and the Knights Ferry County Bridge, four riffles (TMA, TM1, TM2, and TM3) were identified near the Two-Mile Bar Recreation Area (RM 57). Downstream of the Knights Ferry County Bridge toward Riverbank, 106 riffles were marked during 1,500 cfs pulse flow surveys with a numbered 3-inch orange square that was nailed to either a tree or woody debris near the upstream boundary of each riffle. The riffle immediately upstream of the Knights Ferry County Bridge was identified as "R1." The other riffles were sequentially numbered in a downstream direction from there. During subsequent redd surveys conducted when flows were reduced to about 300 cfs, an additional 26 riffles and four small gravel berms were identified. These areas were identified by adding a letter to the upstream riffle's number. For example, an unmarked spawning area downstream of Riffle R2 was called Riffle R2A.

From the 140 riffles and spawning areas identified in the spawning reach in 1995, 18 sites for gravel addition and 7 control riffles were selected for the KFGRP (Table 1 in Appendix 2). The 18 project sites were classified into three categories based on the height of the riffle's crest (hydraulic control). However, since the proposal was prepared during the summer of 1997, gravel movement occurred at several sites that changed the height of the riffle's crest. Besides the change in the riffle's crest, the original classifications were based on elevations measured on a single transect along the length of the riffle, which are not as useful as the contour maps made in August 1999 that show the topography of the entire streambed. Based on the August 1999 data, riffles R10, R14, and R19A were reclassified from moderate-crested riffles to low-crested riffles, and riffles R13, R20, and R43 from low-crested riffles to moderate-crested riffles. Riffle R15 was reclassified from a high-crested riffle to a moderate-crested riffle. The locations of the KFGRP study riffles are shown on USGS quadrangle maps in Appendix 1. Spawner use and incubation conditions were previously monitored at KFGRP riffles TM1, R10, and R27 in fall 1995 (CMC and others 1996) and at KFGRP riffles R10, R14, R29, R43, R58, and R78 in fall 1996 (CMC 1997).

SPAWNER USE

Redds were identified as disturbances in the substrate; they typically have a shallow pit or depression in the upstream half of the disturbed area and a mound of gravel at the downstream half of the disturbance called a tailspill. Most redds were approximately five feet wide by 10 feet long. After it appeared that a redd had been completed, a numbered 2-ounce lead sinker with orange flagging was placed in the redd's pit for identification. Marking was necessary because algal growth and sediment movement progressively made it more difficult to distinguish some of the redds within 10 to 20 days after the female stopped tending the redd.

Redd locations were mapped at each riffle by means of reference to either 2-foot long reinforcing bars driven into the ground or nails driven into trees on both sides of the river. A transect was established at each riffle by running a tape measure from the pin on the left bank (facing downstream) to the one on the right bank during all surveys. A second tape measure was then run from the redd to the transect so that both tape measures were perpendicular to each other. The distance in feet from the pin on the left bank along the transect to the tape measure from the redd was recorded at the station. The distance in feet from the redd to the transect and the direction (upstream or downstream) from the transect were also recorded. These coordinates were plotted on a contour map of each site made from measurements surveyed in August 1999.

STREAMBED ELEVATION AND CONTOUR MAPPING

Relative elevations were measured along the streambank and channel bottom at the same locations at five-foot intervals, at major changes in grade, and at the water surface elevations at the existing flow of 500 cfs along a transect in each riffle in November 1998 with a Sokkia auto level and again in August 1999 with a Nikon DTM-310 total station. The water surface elevation at a flow of about 1,800 cfs which was marked at the water's edge with a wooden stake on 17 and 18 October 1998 was also measured in November 1998. Elevations of the pins or nails used to string the tape measure marking the transect were also measured during each survey as reference points. Photos were taken of each transect with the tape measure strung to help reset pins disturbed by vandalism, beavers, and high flows.

In August 1999, the total station was also used to map the entire riffle and adjacent streambanks by measuring elevations in a 15- to 20-foot grid pattern. At some sites it was not possible to survey the entire site from one location due to the dense vegetation along the streambanks and so the total station was set at two locations, usually on opposite sides of the river. Two 18-inch long steel headstakes were driven into the ground and the elevation of the top of the stakes were measured as reference points, called backsights in the maps in Appendix 1. Measurements at the backsights permitted data sets to be combined that were collected at different total station locations within the same riffle and permitted comparisons of data sets collected in different years. Elevations measured in deep water were made with a raft tethered to a rope stretched across the river.

The Nikon total station has an angle accuracy of five seconds, which provides elevation measurements accurate to within 0.03 inches at a distance of 100 feet. The elevation data were collected as X, Y, Z coordinates that were stored electronically within the total station and then downloaded to a laptop computer. A software program called "Transit" was then used to convert the data into AutoCAD DXF format files. The DXF files were then imported into a software program called Terrain Version 3.1 developed by Softree Technical Systems to generate the contour maps in one-foot intervals. The contour maps show the location of each measurement as a cluster of four small dots.

All elevations measured in November 1998 and August 1999 were adjusted to correspond to the height of the measurements recorded with a total station in December 1999. Therefore, the bed and water surface elevations of the transects presented graphically in Appendix 4 match those in the contour maps in Appendix 3.

The gradient of the streambed upstream of each riffle's crest and upstream from the standpipes were estimated using the contour maps. After the maps were oriented in the Terrain program so that the flow was parallel with the x-axis of the map, the gradient was estimated as the change in elevation divided by the distance between the riffle's crest and another data point 15 to 100 feet upstream of the crest. The gradient upstream of the standpipes was determined using the data point at the standpipe and another datum from 10 to 30 feet upstream of the standpipe.

SUBSTRATE PERMEABILITY

Substrate permeability, which was measured at the study sites in August 1999, depends on the composition and degree of packing of the gravel and the viscosity of the water (as related to water temperature) and reflects "the ease with which water can pass through it" (Pollard 1955). Measurements were made with standpipes that were similar to the Terhune Mark IV permeability standpipe (Barnard and McBain 1994). Two standpipes were constructed for these measurements, one 4.5 feet long and the other 5.5 feet long. They were made of 1.12-inch (28 mm) inside diameter schedule-40 stainless steel pipe with a 3-inch long solid stainless steel driving tip at one end. Above the driving tip, there is a three-inch long cavity to store sand that enters the pipe during sampling. Immediately above the cavity, there is a three-inch long band of perforations around the standpipe. The perforations are 0.12 inch (3-mm) diameter holes, spaced 0.75 inches apart in columns of four holes. A 0.08-inch (2-mm) wide groove was cut about 0.08 inches deep along each of the columns to prevent sand grains from plugging the holes. There are a total of 12 rows of holes and every other column is offset by 0.375 inches to stagger the holes. A one-inch thick driving head is inserted into the standpipe when driving it into the streambed.

The standpipe was driven 19.5 inches into the streambed so that the holes are about 12 inches below the surface of the substrate.

Permeability measurements were made with a homemade pumping device that employed a 12-volt DC battery and a 35 psi diaphragm vacuum pump (Thomas, model #107CDC20-975C) to draw water into a cylindrical vacuum chamber, 2.75 inches in diameter and 20 inches long. The device was mounted on a backpack frame. Two 3/8- inch polypropylene hoses were used, one to connect the pump to the vacuum chamber and the other to draw water from the standpipe into the vacuum chamber. A 1/4-inch inside diameter plastic tube and a fiberglass tape with gradations in centimeters was attached to the side of the vacuum chamber to measure the change in height (i.e., volume) of the water drawn into the vacuum chamber. For each one-centimeter change in water height in the chamber, 39.8 ml were drawn into the chamber.

To measure permeability, the pump was switched on, and the hose was slowly lowered into the standpipe until a slurping noise was heard indicating that there was contact with the water. A one-inch spacer was then placed on top of the standpipe and a clamp was attached immediately above the spacer to the side of the hose without constricting it. The pump was then switched off, the spacer removed, and the hose lowered until the clamp rested on top of the standpipe. This placed the end of the hose one inch below the water's surface in the standpipe. The pump and a stopwatch were then switched on simultaneously until about 800 ml of water was collected in the vacuum chamber. Smaller volumes were collected at sites with very slow pumping rates. In those cases, pumping occurred for at least one minute. At the end of pumping, the stopwatch was turned off at the same time the hose was lifted from the standpipe. Then, pumping was continued until all of the water in the hose had passed into the vacuum chamber. Water temperature was also measured at the same time with an Extech electronic thermometer to the nearest 0.1^{o}C to determine a viscosity correction factor.

Inflow rate, the ratio of measured water volume per unit time, was computed by first correcting for the initial 1 inch of water collected and the time required to collect it. The volume of the 2.5 cm of water, which is 15.64 ml for the 28 mm pipe, was subtracted from the measured volume, and the time taken to remove it from the standpipe, estimated at 0.1 seconds, was subtracted from the measured time. The sample permeability was then interpolated from an empirical permeability versus a corrected inflow rate calibration table (Table 2 in Appendix 2). The calibration table provides conversions up to 110.9 ml/sec for field inflow rates whereas higher rates were measured at the restoration sites and in redds. Conversions were made for readings that exceeded 110.9 ml/sec by increasing the permeability by 500 cm/hr for each 0.1 ml/sec increase in the field inflow rate beyond 110.9 ml/sec. For example, a field inflow rate of 111.0 ml/sec was converted to a permeability of 105,000 cm/hr. After the field inflow rates were converted to a permeability value, the permeability value was standardized to a temperature of 10^{o}C by the viscosity correction factor presented in Barnard and McBain (1994).

INTRAGRAVEL DISSOLVED OXYGEN CONCENTRATION

One intragravel D.O. sample was collected from each of 77 sites in the undisturbed substrate of most project and control riffles between 28 November and 6 December 1998 and again at approximately the same 77 sites plus 46 more between 2 and 24 August 1999. No samples were collected at riffles R13, R19A, and R57 in fall 1998 because the water was too deep for the standpipe.

Different sizes of standpipes were used for the fall 1998 and summer 1999 surveys. In fall 1998, the standpipe used was a 4.46 foot-long, thin-walled steel pipe, with a 9/16-inch opening at the top that tapered to a hardened point at the bottom, where there were four 1/24-inch diameter holes. It was fashioned from a ski pole that had its handle and basket removed. The standpipe was driven into the streambed by inserting a 1/2-inch bolt into the top and then driving it into the substrate with a 4-pound hammer so that the four intake holes were 12 inches below the substrate's surface. Sampling locations were recorded using the same coordinate system used for the redd surveys. After the standpipe was driven into the substrate, the bolt was removed and a 1/8 inch inside-diameter polypropylene tube was inserted into the standpipe so that its end was about 2 inches below the water's surface. A 50-ml polypropylene disposable syringe was used to withdraw at least 250 ml of water from the standpipe. Because the standpipe filled slowly, withdrawing the 250 ml of water removed most or all of the surface water and filled the standpipe with intragravel water. After the surface water had been withdrawn, the water in the standpipe was left undisturbed for about 5 minutes to allow substrate fines to settle. A 60-ml sample was then withdrawn from near the bottom of the standpipe and fixed for a D.O. analysis using a LaMotte test kit, model EDO/AG-30. The LaMotte test kit uses the azide modification of the Winkler Method. After the D.O. samples were fixed, they were placed in an ice chest and analyzed at room temperature within 10 hours.

During August 1999, the 4.5 and 5.5 ft-long gravel permeability standpipes were used to collect D.O. samples. The D.O. samples were collected after the gravel permeability was measured and up to 5 liters of water had been pumped out to minimize suspended organic matter and fines in the standpipe. After pumping, the water was allowed to clear for about one minute before a 60-ml D.O. sample was collected from near the bottom of the standpipe. The sample was fixed and analyzed using a LaMotte test kit, model EDO/AG-30.

A surface D.O. sample was collected at each site at the same time the intragravel samples were collected. The percent saturation of dissolved oxygen for the intragravel samples was computed by dividing the D.O. concentration of the intragravel sample by the D.O. concentration of the surface sample.

A review by Chapman (1988) indicates that the oxygen requirement of salmonid eggs gradually increases from fertilization to hatching, reaching a maximum of 5 ppm at 10ºC by the stage of development at 250 degree-days (one degree-day equals 1ºC above 0ºC for 1 day). However, Davis (1975), who also reviewed the oxygen requirements of salmonids, reported a mean threshold of incipient oxygen response for hatching eggs and larval salmonids at 8.1 ppm and 76% of saturation. D.O. requirements of eggs and larval salmonids are higher when the effects on growth are considered. The growth of chinook salmon embryos was reduced at D.O. concentrations less than 11.7 ppm (Silver and others 1963). Chapman (1988) suggested that any reduction in D.O. level from saturation probably reduces survival to emergence or post-emergent survival. Reduced size of alevins would reduce their ability to break through sand barriers during emergence and reduce their ability to compete for habitat and food with larger fry. For this study, 5 ppm was used as the critical level for egg mortality and 8 ppm was used as the critical level for egg development and alevin growth.

VERTICAL HYDRAULIC GRADIENT

The ratio of the differential head to the depth of the piezometer below the sediment-water interface (Lee and Cherry 1978; Dahm and Valett 1996) is known as the vertical hydraulic gradient (VHG). Negative VHG measurements indicate the downwelling of surface flow and positive values indicate the upwelling of intragravel flow. VHG was measured at each standpipe in November 1998 and August 1999. The differential head is measured with a manometer consisting of a 9-ft long, 1/8-inch inside-diameter, clear tube. One end of the tube of the manometer is inserted into the standpipe to about one inch above its bottom, which is pounded about 12 inches below the substrate surface, and the other end of the tube, attached to a wooden stake is held near the substrate’s surface (Lee and Cherry 1978; Dahm and Valett 1996). A silicone pipet bulb with emptying and filling valves is attached to the middle of the tubing with a t-connector to facilitate filling the manometer with water. Measurements are made by partially filling the manometer's tubing with water and then holding the middle of the tube at eye level to form a loop with two vertical tubes and a single air bubble at the top of the loop. Before the measurement is made, the manometer is inspected to ensure that there are no air bubbles trapped in the water columns or fine sediment/debris blocking flow through the tubes. The differential head is read as the difference in height between the water levels in the two tubes. Measurements are negative when the water level in the side of the tube inserted in the standpipe is lower than the level in the side of the tube held at the substrate’s surface. VHG is computed as the differential head divided by 12 inches, which is the approximate difference in elevation between the holes in the standpipe and the substrate’s surface.

Measurements made in areas with very low permeabilities were discarded because once the standpipe holes were plugged with fine sediments, a false negative head was created in the standpipe by continuing to drive the standpipe deeper into the substrate. This was verified at questionable standpipe locations by adding water to the standpipe after the first measurement was taken. If the standpipe’s pores were plugged, the elevation of the water’s surface within the standpipe would remain at an increased level from the added water. Otherwise, the water level in the standpipe would gradually return to its original level and the measurement was recorded.

SUBSTRATE BULK SAMPLES

The bulk sampler was an 18-gauge stainless steel cylinder, 18 inches in diameter and 42 inches high, with handles and a serrated bottom. It was pushed into the streambed to a depth up to 12 inches at a permeability standpipe location. A shovel with the edge of its blade modified to fit tightly against the inside of the bulk sampler was used to excavate the substrate. Bulk substrate samples were placed in five-gallon buckets that were sealed with lids for transport to the laboratory. The upper substrate layer was stored and analyzed separately from the lower subsurface layer. Samples were typically collected at two to three sites in each riffle where permeability and D.O. were measured in August 1999. However, at riffles R12A, R13, R14, R16, R19A, R57, and R59, either no sample or one bulk sample was collected because the water was too deep.

All samples were dried and then sieved in eight-inch diameter Gilson U.S.A. Standard Testing Sieves. Sieve sizes used were 63, 31.5, 16, 9.5, 8, 4, 2, 1, and 0.85 mm. Samples were sieved to

31.5 mm by hand shaking and then to 0.85 mm for five minutes with a mechanical shaker. The weight of the material caught on each sieve and in the pan was usually measured to the nearest gram on an Acculab electronic digital scale, model 2001. Large rocks that exceeded 2.2 kg were weighed on a Chatillon hanging spring scale that measured in 200 gram increments. The diameter of the largest rock in each sample was estimated based on the size distribution curves in Appendix 4 and so extrapolations to estimate the diameter at which 84% (d_{84}) of the sample is finer may not be accurate.

Sediment particle size distribution was determined using a Quatro Pro spreadsheet to compute the percent weight of each particle size fraction (weight of substrate collected on an individual sieve divided by total sample weight) and the "cumulative percent finer", which is the percent by weight of the sample that is smaller than a given sieve size.

Size descriptors estimated for the substrate samples, which are recommended by Kondolf (2000), include:

- Median diameter (d_{50}) of the entire surface sample to assess the ability of salmon to move the substrate,
- percent finer than 6.35 mm for the entire surface sample to assess the probability of emergence, and
- percent finer than 1 mm for the entire subsurface sample to evaluate correlations with permeability.

STATISTICAL ANALYSES

All statistical analyses, including *t* tests, correlations, and regressions, were made using the Statistix Version 7.0 software program (Analytical Software).

RESULTS

The Department of Fish and Game's preliminary estimate of chinook salmon escapement (grilse and adults) to the Stanislaus River in fall 1998 was 3,147 fish (Heyne, 14 June 2000). During the previous studies conducted for the Stockton East Water District in fall 1994, 1995, and 1996, escapement estimates were 1079, 611, and 168 respectively (Mesick 2001b).

SPAWNER USE

A total of 620 redds was observed at the 25 KFGRP riffles in fall 1998 (Table 3 in Appendix 2). Spawning began earlier in fall 1998 than in previous surveys. By 1 November 1998, 25% of the total number of redds had been counted. In comparison, only 7% of the redds in fall 1994 and 9% of the redds in 1995 had been observed by early November. During the last survey on 13 December, only 13 fresh salmon were observed between riffles TMA and R20 and all were in the process of redd construction. The density of all redds constructed between 30 October and 13 December was highest (0.186 per square-yard) near riffle R1 at the Knights Ferry Bridge and gradually declined from there both in an upstream and downstream direction (Figure 2).

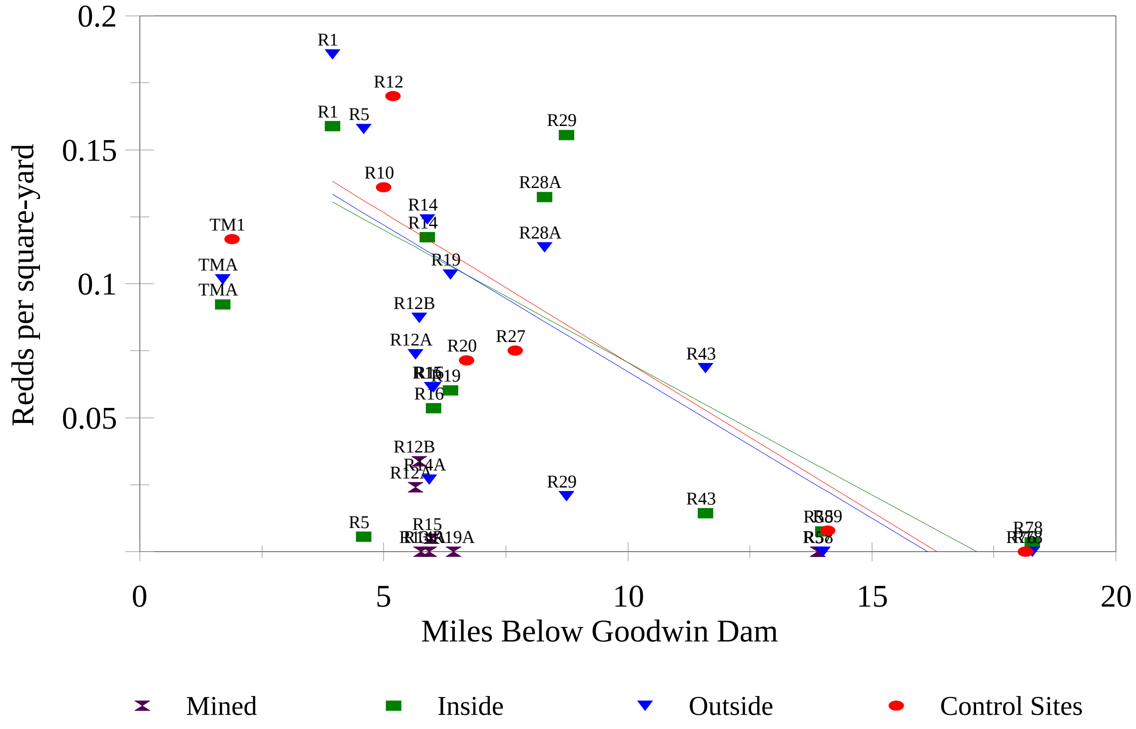

Figure 2. Chinook salmon redd densities at control sites, "outside" gravel addition areas of unmined project sites, "inside" gravel addition areas of unmined project sites, and "mined" project sites relative to the distance below Goodwin Dam in the Stanislaus River in fall 1998.

Redd densities at the control riffles were similar to those in the unmined project sites, but much higher than at areas within project sites that were mined. At project riffles R12A, R12B, R13, R14A, R15, R19A, and R57 where gravel mining produced a silty, compacted, and usually flat streambed in 6 to 10 foot deep water, redd densities were low, averaging 0.023 redds per square-yard (Table 3 in Appendix 2). Redd densities were even lower when estimated for the specific areas that were mined where restoration gravel was to be placed in fall 1999. In the mined areas of the project riffles, which are identified as "inside" the gravel addition area in Table 3 (Appendix 2), average redd densities were 0.010 per square-yard for the above seven mined sites (Figure 2). In contrast, average redd densities were much higher, 0.079 per square-yard "outside" of the gravel placement area of the 18 project riffles where gravel remained, 0.079 per square-yard "inside" the gravel placement area of the 10 unmined project sites, and 0.082 per square-yard at the seven control sites (Table 3 in Appendix 2 and Figure 2).

To test whether the differences in redd density between the control sites, mined areas, and the unmined areas inside and outside of the project sites were statistically significant, redd densities were first regressed against distance below Goodwin Dam and then the residual variances, slope, and elevations of the regressions were compared with two-tailed *F*-tests (Snedecor and Cochran 1989, pages 390-393). The slopes and adjusted-R^2 of the regressions of redd density and miles below Goodwin Dam for all sites except those at Two-Mile Bar are presented in the table below:

Dependent Variable	n	Adj-R^2	Slope	*F* statistic	Probability (*P*)
Control Sites	6	0.746	-0.0112	15.7	0.017
Outside Sites	14	0.426	-0.0095	10.64	0.007
Inside Sites	9	0.128	-0.0067	2.17	0.184
Dredged Sites	8	-0.115	-0.0008	0.28	0.617

The *F*-tests indicated that there were no significant differences ($F \leq 3.16$ and $P \geq 0.141$) in the residual variances, the slopes, or the elevations of the regressions for the control and the "outside" sites and the "inside" unmined sites. It was not possible to compare the redd densities at the mined project sites with those at the control sites and the unmined project sites because redd densities at the mined sites were not significantly correlated with distance downstream and the variance was high for the regression. The *F*-test for the comparison of the regression with the control sites and the mined project areas indicated that there is a significant difference in the residual variances ($F = 7.05$, $df = 4, 7$, $P = 0.013$) which precludes any comparison of adjusted means derived from the regression slopes and elevations.

The regression between the density of redds at the unmined project and control riffles between R1 and Riverbank and the distance below Goodwin Dam appear to have a much steeper slope in fall 1998 (-0.0126) than occurred in fall 1994 (-0.0014), fall 1995 (-0.0012), or fall 1996 (-0.0022; Figure 3). There were three differences in redd distribution between fall 1998 and the 1994 to 1996 redd surveys: first, from 1994 to 1996, the density of redds was very high at Riffle TM1 and moderate at Riffle R1 in comparison to downstream riffles; second, redd densities were relatively similar between riffles R2 and R43 from 1994 to 1996; and third, few salmon spawned more than 14 miles below Goodwin Dam in 1995, 1996, and 1998, whereas in 1994, when escapement was about one-third the estimate for 1998, salmon spawned in almost every riffle as far as 23 miles below Goodwin Dam. However, the slopes of the regressions for redd density versus distance below the dam for the 1994 through 1996 redd surveys are not statistically comparable to the regression with the fall 1998 data using *F*-tests. For all three comparisons, the *F*-test indicated that the residual variances were significantly different as the variance was much higher for the 1994 through 1996 regressions when escapements were low compared to the fall 1998 regression when escapement was high. Because the variances were significantly different, the assumption of the *F*-test was violated and the regression slopes could not be compared.

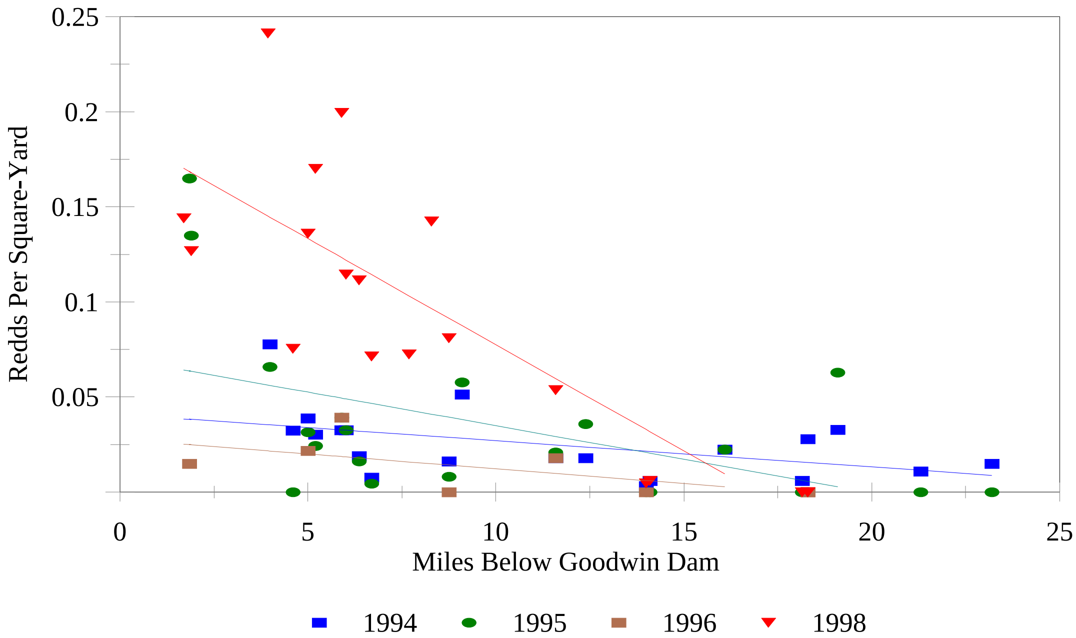

Figure 3. The relationship between chinook salmon redd density at unmined sites and the distance below Goodwin Dam in fall 1994, 1995, 1996, and 1998. The regressions for these relationships are shown by the four lines.

Redd superimposition was not directly monitored in fall 1998, although it probably occurred. In fall 1996, 24% of 21 redds monitored were superimposed as evidenced by displaced standpipes driven into the egg pockets, a surprising result considering that escapement was estimated at only 168 fish (Mesick 2001a). Because escapement was 18 times higher in fall 1998 than in 1996, it is likely that redd superimposition would have exceeded 24%. Although many of the redd markers at the upstream riffles (TMA to R43) were buried or displaced, it was not always possible to determine whether the original female salmon moved the marker while tending her redd, redd superimposition had occurred, or a boater moved the marker. In some cases, boaters had collected a few markers and placed them on the streambank. Superimposition can result in direct egg mortality if the late-arriving female digs up the eggs in pre-existing redds. Another more frequent impact of superimposition in the Stanislaus River probably occurs when redds are constructed immediately upstream of other redds depositing fines on the pre-existing redds that smother the developing eggs and hinder emergence (Mesick 2001a).

A total of 43 redds were observed at the DFG restoration site in upper Goodwin Canyon, referred to as DFG2 in this report, in fall 1998. The gravel was placed at a site that was approximately 80 feet wide by 60 feet long in 1997. By fall 1998, some of the gravel in the center of the riffle had been flushed away by high flows and so there was about 144 square yards of spawning habitat there in fall 1999. The density of redds at DFG2 was 0.30 per square-yard, which was much higher than the densities observed at any of the KFGRP sites.

STREAMBED ELEVATION AND CONTOUR MAPPING

Redd densities were computed from the electronic files used to generate the contour maps for each of the KFGRP riffles in Appendix 3. Each map shows the contour of the streambed and streambank in one-foot intervals, the locations of redds, the transect where elevations were measured in five-foot intervals, and the backsights.

There were no substantial changes in the streambed between mid-November 1998 during the spawning surveys and August 1999 when streambed elevations were measured for the contour maps, permeability rates were measured, and intragravel water quality samples were collected. Streambed elevations along the transects were nearly identical in November 1998 and August 1999 for most sites (Appendix 4). Most of the changes in bed elevation between the two surveys were probably due to redd construction or a slight change in the location of the transect when the reinforcing bars or nails were disturbed. Bed elevations decreased by 0.2 to 0.85 feet where salmon were spawning near the transect at riffles TM1, R14 R19, R20, and R28A. A 1.3-foot decrease at one point on the left bank of riffle R10 was probably caused by a slight shift of the transect after the left pin had to be replaced because the cottonwood tree with the original pin fell over. Other transects may have moved slightly because the left pins had to be reestablished due to vandalism at riffles R1 and R43 and because high winter flows disturbed both pins at riffles R28A, R58, and R78. At the three riffles where both pins were disturbed, there were no permanent benchmarks with known elevations available, so the data from November 1998 were adjusted to match the water surface elevations measured at the transect (flows were 500 cfs during both surveys) and at several stations along the transect that were on dry streambank where erosion or deposition were unlikely.

Some of the streambed elevations at Riffle R76 in November 1998 were measured downstream of the transect due to the difficulty of working in swift and deep water and so those data are not shown in Appendix 4. However, the measurements taken near the streambank were measured along the transect and those data suggest that there was no change in stream width.

SUBSTRATE PERMEABILITY

The August 1999 mean permeability rate in undisturbed gravel was 3,129 cm/hr for riffles between TMA and R27, whereas most measurements in this reach ranged between 1,000 to 3,000 cm/hr (Table 4 in Appendix 2). The permeability rates were lower in the downstream riffles between R28A and R78 averaging 779 cm/hr (range of 80 to 1,500 cm/hr). There were unusually high permeability rates between 5,032 and 13,359 cm/hr at some of the standpipe sites in riffles R10, R12, R12A, R12B, R13, R19, R19A, R20, and R27. However, low rates frequently occurred within the same riffles. At standpipes P3, P4, P5, and P6 at Riffle R27 where restoration gravel was placed in 1994, the average permeability was 4,193 cm/hr (range of 779 to 6,927 cm/hr).

In comparison, the permeability rates of five redd tailspills measured after they were constructed in December 1999 ranged between 38,512 and 204,000 cm/hr (mean 143,322 cm/hr) in riffles R10 and R12, which are control riffles, and at standpipes 5 and 6 at Riffle R19, which were downstream of the restoration gravel. The tailspill with a permeability of 38,512 cm/hr was probably constructed well before the measurement was taken and the permeability probably declined as fine sediment intrusion occurred from the nearby construction of other redds. Permeabilities would also be expected to decline from the migration of fines within the streambed (Mesick 2001a) and during storms when turbidity increases.

INTRAGRAVEL DISSOLVED OXYGEN CONCENTRATION

The mean intragravel D.O. concentration in fall 1998 was 9.5 ppm, which was 79% of saturation. In August 1999 it was only 7.0 ppm, which was 66% of saturation, at the same 77 standpipe sites measured in fall 1998 (Table 4 in Appendix 2). The differences between fall 1998 and August 1999 were significant (t = 5.29, df = 74, P = 0.000) based on a paired t-test. Possible causes of the low percent of saturation in August 1999 compared to fall 1998 include an increase in the inflow of oxygen-poor groundwater, an increase in the oxygen demand of the organic material in the substrate, or a decrease in the flow of surface water into and through the substrate in August 1999 (Bjornn and Reiser (1991).

In fall 1998, intragravel D.O. concentrations were greater than 8 ppm ($\geq$64% of saturation) at 82% of the 77 standpipe sites, between 5 and 8 ppm at 9% of the 77 standpipe sites, and below 5 ppm at 8% of the sites (Table 4 in Appendix 2). Concentrations below 8 ppm occurred at riffles R12, R12B, R14A, R27, R28A, R29, R43, R58, R59, and R76. Concentrations below 5 ppm occurred at all standpipe sites at R14A, one site at R27, and most of the sites at R29. The concentrations observed in fall 1998 were similar to those in fall 1995 and 1996. In November and December 1995, the average D.O. concentration was greater than 8 ppm at 78% of 32 minipiezometer sites, between 5 and 8 ppm at 16% of the sites, and less than 5 ppm at 6% of the sites (CMC and others 1996). In mid November 1996, the average D.O. concentration was greater than 8 ppm at 71% of 27 minipiezometer sites, between 5 and 8 ppm at 22% of the sites, and less than 5 ppm at 7% of the sites (CMC 1997).

To compare D.O. concentrations between fall 1998 and summer 1999, the percent of saturation was used to compensate for the effects of the higher water temperatures in summer 1999. The criteria of 5 ppm for direct mortality of eggs and alevins and 8 ppm for substantially reduced growth would be equivalent to 42% and 64% of saturation respectively for the fall 1998 samples.

In August 1999, D.O. was greater than 64% of saturation (typically about 7 ppm) at only 60% of the 123 standpipe sites, between 42% and 64% of saturation at 15% of the sites, and below 42% of saturation (typically about 4.6 ppm) at 22% of the sites (Table 4 in Appendix 2). Riffles where most of the standpipe samples were below 64% of saturation include R10, R12, R12A, R14A, R15, R19A, R28A, R29, and R76. On the other hand, readings of at least 90% of saturation occurred at all standpipe sites during both the fall 1998 and summer 1999 surveys at only Riffle R20.

The average intragravel D.O. concentration at four standpipes at DFG2 was 12.1 ppm or 99% of saturation on 6 December 1998. This was similar to the concentrations observed at riffles R19 and R20, but substantially higher than the other KFGRP riffles.

DISSOLVED OXYGEN IN SURFACE FLOWS

The average D.O. concentration of the surface flow measured on 28 and 29 November and 4 December 1998 was 11.8 ppm for the riffles between TMA and R27, which is 7.7 miles below Goodwin Dam, but then abruptly declined to 11.1 ppm for the riffles between R28 to R78. In 1995 and 1996, D.O. was also highest in the upstream riffles although the location where it declined varied throughout the spawning season. In 1995, the average D.O. upstream of R27 was 11.6 ppm whereas it averaged 10.5 ppm downstream from there during three surveys in November. There was typically a sharp decline in D.O. between Riffle R27 and R32, which is 9.1 miles below Goodwin Dam. By mid December 1995, the high D.O. concentrations had extended to Riffle R47 which was 12.4 miles below Goodwin Dam. During the 1996 surveys, D.O. gradually declined in a downstream direction: from 12 to 11.5 ppm in late October and early November and from 10.8 to 9.6 ppm on 19 November. The patterns of D.O. observed in the Stanislaus River cannot be explained by surface water temperatures alone and are probably related to turbulence associated with high gradient riffles present primarily in the upper reaches and the accumulation of decaying organic matter from agriculture and housing that exists along most of the river below Riffle R1. Although there is no significant correlation between redd densities and surface D.O. concentrations in fall 1998, it is possible that the fish migrate upstream until they detect a minimum D.O. concentration before they select a spawning site. If this is true, then salmon that enter the river to spawn early in the season may migrate farthest upstream to find suitable D.O. compared to salmon that enter late in the season. This would explain why the late-arriving fish in 1994 spawned throughout the usable riffles whereas the early-arriving fish in 1998 were concentrated in riffles between TMA and R20. In fact 86% of the salmon in fall 1998 spawned between riffles TMA and R20, a small span of only 5 miles and 21 riffles in relation to the entire spawning reach which is 25.5 miles long and contains 140 riffles. Further studies are needed to determine whether the salmon’s migrations to the spawning areas are controlled by D.O. or some other factor.

VERTICAL HYDRAULIC GRADIENT

The average VHG was 0.113 for the 76 standpipe sites measured in fall 1998 and -0.009 for the 120 standpipe sites measured in summer 1999 at the KFGRP riffles (Table 4 in Appendix 2). The differences between fall 1998 and August 1999 were significant (t = 9.27, df = 75, P = 0.000) based on a paired t-test. Most of the readings in fall 1998 were positive indicating that upwelling was occurring at most locations in the Stanislaus River during spawning, a result that also occurred in fall 1996 (Mesick 2001a). In both fall 1998 and August 1999, negative readings of VHG, which indicate downwelling, were strongest where the streambed was relatively flat (Figures 4 and 5). Although the lowest average VHG, 0.0625 in fall 1998 and -0.028 in August 1999, occurred at standpipe sites where the gradient ranged between zero and 0.5%, these averages were not significantly different from those where the streambed gradient was negative or highly positive based on F-tests. Typically, VHG is negative upstream of the hydraulic control such as in the tail of a pool where the gradient is positive, and near zero where the streambed is flat (Lee and Cherry 1978; Creuze des Chatelliers and others1994, Dahm and Valett 1996).

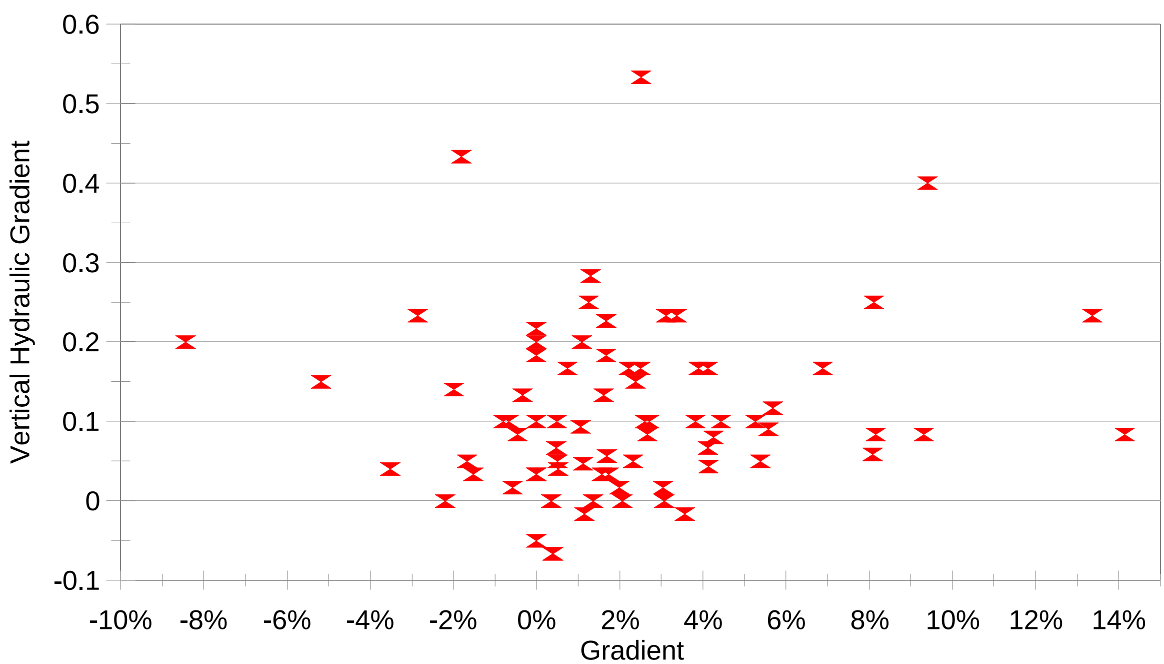

Figure 4. Vertical hydraulic gradient measured at 76 standpipe sites relative to streambed gradient 10 to 30 feet upstream of the standpipe in 25 Knights Ferry Gravel Replenishment Sites in the Stanislaus River in fall 1998. Negative gradients indicate that the streambed was falling in a downstream direction.

The VHG ranged from 0.167 to 0.333 (mean 0.24) at four standpipes at Riffle DFG2 on 6 December 1998. These readings indicated that relatively strong upwelling was occurring at DFG2 compared to most of the KFGRP sites in fall 1998.

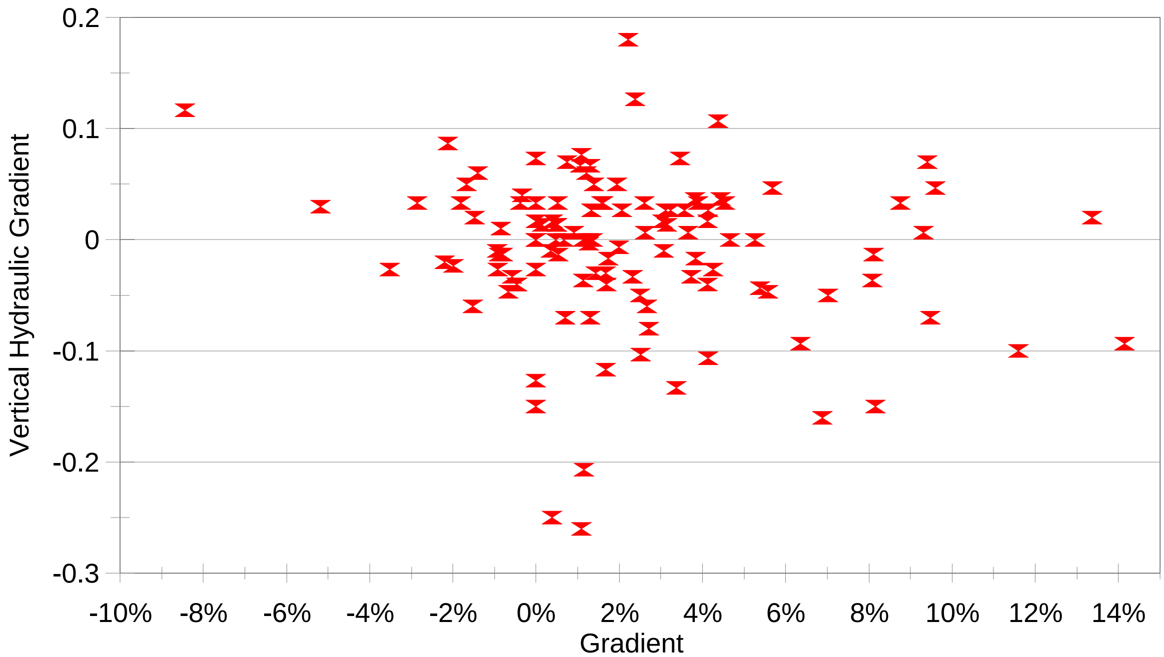

Figure 5. Vertical hydraulic gradient measured at 120 standpipe sites relative to streambed gradient 10 to 30 feet upstream of the standpipe in 25 Knights Ferry Gravel Replenishment Sites in the Stanislaus River in August 1999. Negative gradients indicate that the streambed was falling in a downstream direction.

SUBSTRATE BULK SAMPLES

The median diameter (d_{50}) and the percentage finer than 6.35-mm of the surface layer of the 50 bulk samples indicate that chinook salmon can move the sediment during redd construction and that fine sediment was suitable for emergence at most of the study riffles. The d_{50} averaged 36 mm and ranged from 9.5 at Riffle R59 to 105 mm at R19A (Table 5 in Appendix 2). An averaged sized female chinook salmon in the Stanislaus River is about 700 mm long and would typically be expected to select gravel with a d_{50} of about 25 mm, but would spawn in gravel with a d_{50} up to about 70 mm (Kondolf 2000). Only some of the samples taken at riffles R1, R19, and R19A had a d_{50} that exceeded 70 mm.

The percentage of particles finer than 6.35-mm in the surface sample averaged 14.6% and ranged from 0.02% at Riffle TMA to 42.4% at R59 for the 50 bulk samples (Table 5 in Appendix 2). In laboratory studies, alevins of chinook salmon had difficulty emerging from gravel-filled troughs when the percentages of fine sediments less than 6.4 mm exceeded 30 to 40% (Bjornn 1968; Bjornn and Reiser 1991). The percent finer than 6.35-mm in the surface sample exceeded 30%

only at standpipe sites P1 at Riffle TMA, P4 and P6 at Riffle R29, P5 at Riffle R58, and P6 at Riffle R59.

The percentage of particles finer than 1 mm in the subsurface sample averaged 11.3% and ranged from 0.23% at riffle R20 to 35.8% at R29 (Table 5 in Appendix 2). The percentage of fines increased with the distance below Goodwin Dam, however, the Pearson coefficient (*r*) was only 0.32 and the probability level was 0.07. The percentage of fines exceeded 20% at riffles R15, R29, R58, R59, and R78.

The cumulative size distribution curves for the 50 surface, subsurface, and combined bulk samples are presented in Appendix 5. These curves were used to estimate the d_{50} and the percentage finer than 6.35-mm of the surface layer. The weight of substrate particles retained in each sieve and the pan for the surface and subsurface layers of the bulk samples are presented in Table 6 in Appendix 2.

CORRELATIONS

Correlations were analyzed to determine whether habitat features, such as distance of the riffle below Goodwin Dam, streambed gradient, substrate permeability, intragravel D.O. concentration, VHG, and substrate particle size, could be used to characterize spawning habitat for chinook salmon in the Stanislaus River. Another objective of these analyses was to investigate the relationships between the habitat features. Many researchers have reported that substrate gradient, permeability, D.O. levels, VHG, and substrate particle sizes are strongly interrelated (Chapman 1988, Bjornn and Reiser 1991). Perhaps one measure, such as permeability, could serve as an adequate index of spawning and incubation conditions if there are strong correlations among the different measures.

Before the correlations were evaluated, the data were plotted to determine whether nonlinear relationships existed. None were observed, except for those with streambed gradient.

Spawning Habitat

Three indices of spawning habitat were tested that include the density of redds for an entire riffle and the density of redds in both a 10-foot and 20-foot radius around each standpipe location. The three different indices were used because it is likely that the spawning habitat was not saturated and so some locations that were quite suitable for spawning may not have been selected by spawning salmon. In this case, using the density for the entire riffle would minimize the problem that some suitable areas were not selected by chance. On the other hand, there was considerable variability in the habitat features within many of the riffles, and so the redd densities were also measured within a small radius around each standpipe to reflect the variation within and between the riffles. The regression models, student's *t*-value, probability level, and partial correlations for the nonsignificant variables are presented in Tables 7 through 9 of Appendix 2.

All three indices of spawning habitat were most strongly correlated with the distance below Goodwin Dam. Both the density of redds for the entire riffle (Figure 2) and in a 10-foot radius were significantly correlated ($P \leq 0.05$) with only the distance below Goodwin Dam. The distance below the dam explained 46.7% of the variation (*adj*-R^2) in redd densities for the entire riffle (Table 7), whereas distance explained only 21.0% of the variation in redd densities in a 10-foot radius (Table 8).

The density of redds in a 20-foot radius around each standpipe was correlated with the distance below Goodwin Dam (Figure 6), the percentage of substrate particles finer than 1 mm in the subsurface sample (Figure 7), VHG measured in August 1999 (Figure 8), and the intragravel D.O. concentration measured in fall 1998 (Figure 9) based on separate analyses for the fall 1998 and August 1999 data. For the fall 1998 analysis, 34.2% of the variation in redd density was explained by the distance below Goodwin Dam and D.O. (Table 9). A comparison of the *t*-values indicates that distance (t = -5.49) was a more important influence on redd density than was D.O. concentration (t = 2.24). For the August 1999 analysis, 39.2% of the variation in redd density was explained by the distance below Goodwin Dam, the VHG, and the percent finer than 1 mm in the subsurface sample (Table 9). Although the VHG measured in August 1999 was strongly correlated with redd densities, the correlation was positive suggesting that chinook salmon preferred to spawn in areas of upwelling. This is contrary to the findings of many researchers that report that salmonids prefer to spawn in the transitional area between pools and riffles where downwelling currents normally occur (Bjornn and Reiser 1991). Furthermore, because redd densities were poorly correlated with VHG measured in fall 1998, the correlation with the VHG measured in August 1999 is probably false. When the 1999 VHG was dropped from the analysis, the distance downstream and percent finer than 1 mm explained 28.5% of the variation in redd densities.

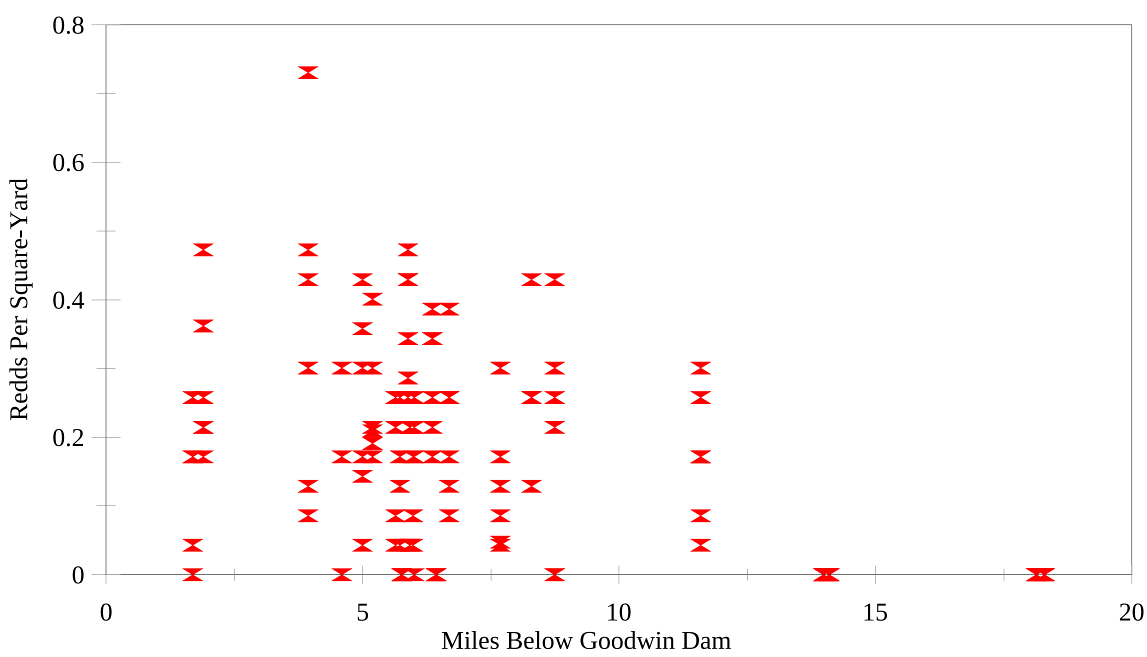

Figure 6. Redd density within a 20-foot radius around standpipe locations in fall 1998 relative to the distance downstream from Goodwin Dam in the Stanislaus River.

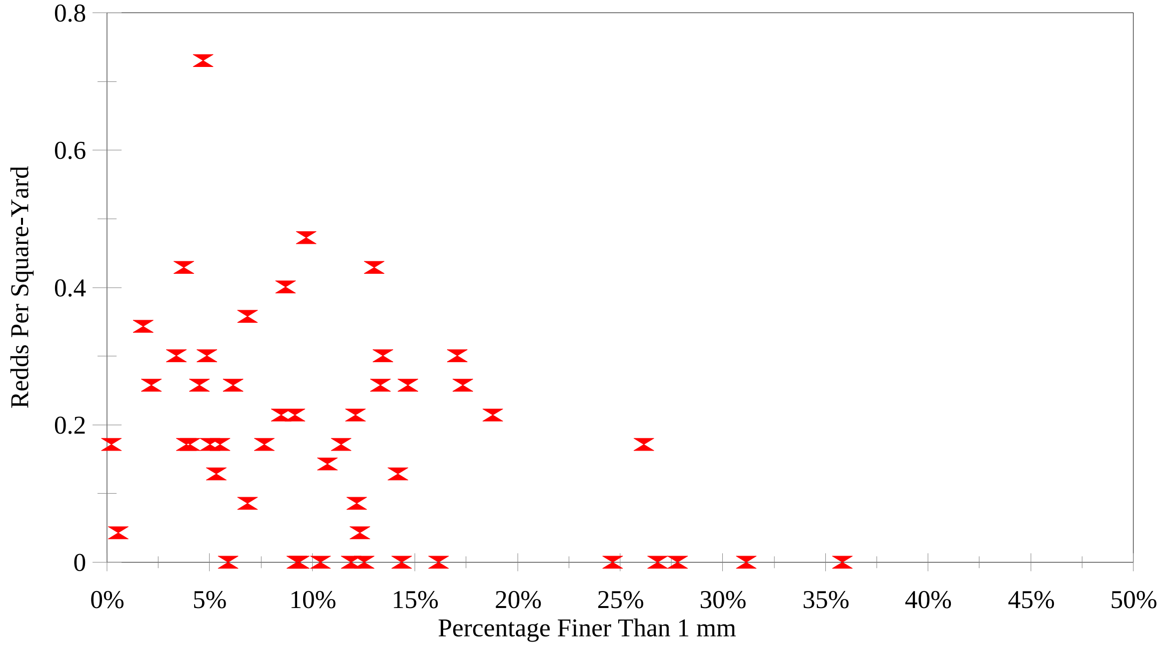

Figure 7. Redd density within a 20-foot radius around standpipe locations in fall 1998 relative to the percentage of substrate particles finer than 1 mm in the subsurface layer of bulk samples taken at the standpipes in August 1999 in the Stanislaus River.

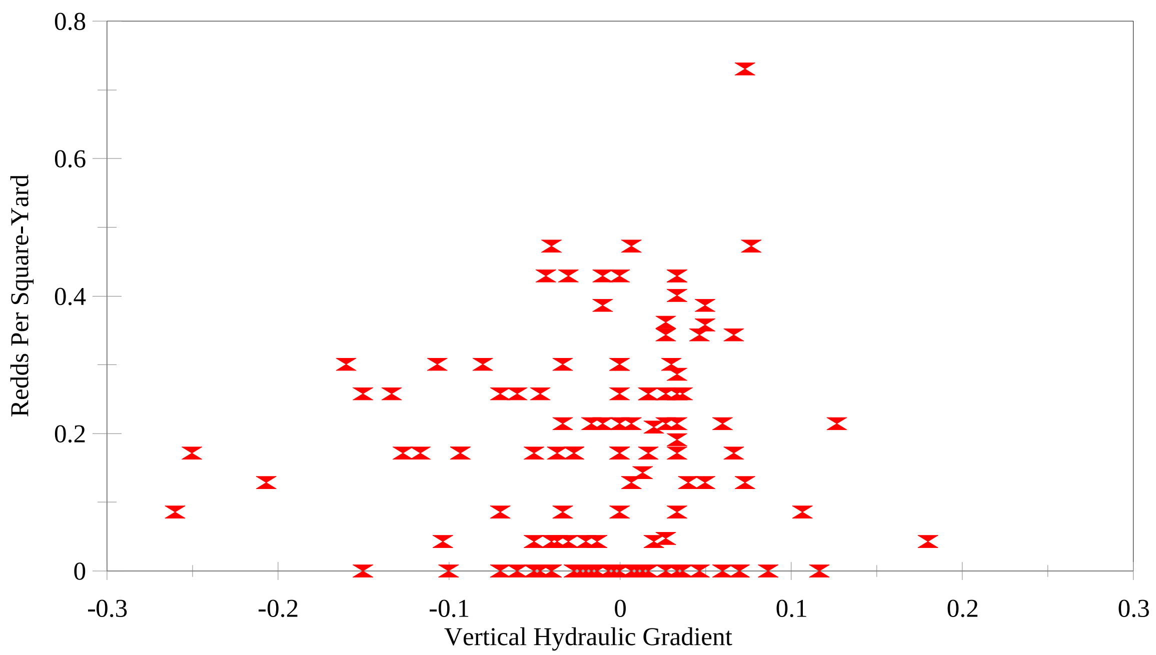

Figure 8. Redd density within a 20-foot radius around standpipe locations in fall 1998 relative to vertical hydraulic gradient at the standpipes in August 1999 in the Stanislaus River.

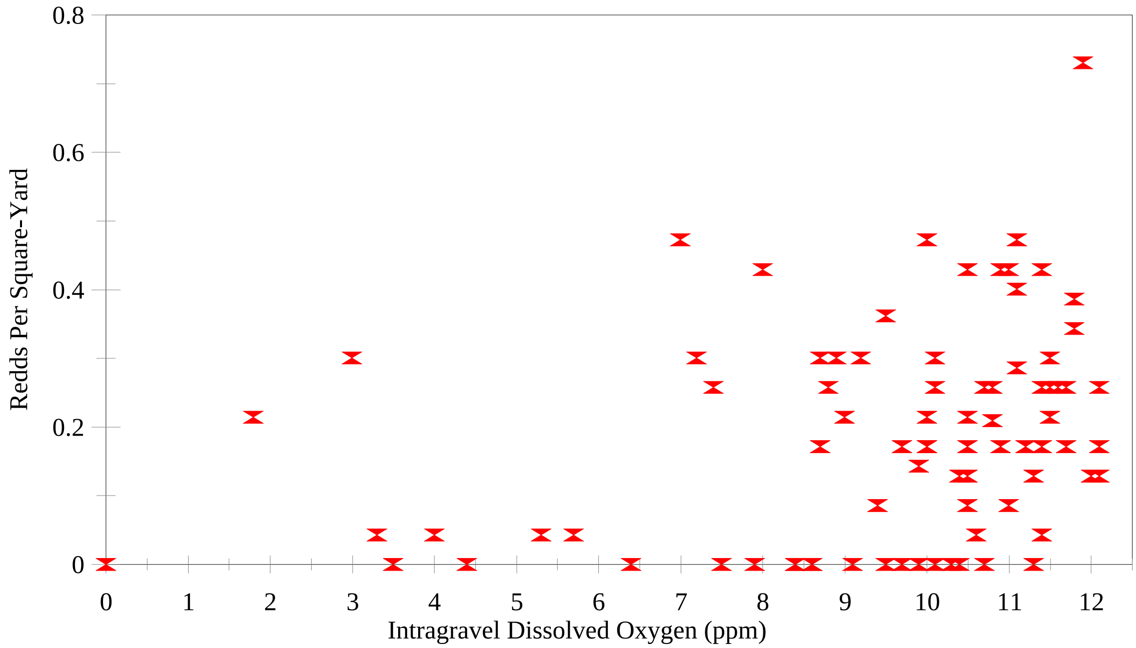

Figure 9. Redd density within a 20-foot radius around standpipe locations in fall 1998 relative to intragravel dissolved oxygen concentrations at standpipes in fall 1998 in the Stanislaus River.

Although very little of the variation in redd densities was explained by distance downstream of Goodwin Dam, percent finer than 1 mm in the subsurface sample, and intragravel D.O., it is likely that the weak correlations were due to low escapement and under utilization of the habitat rather than a lack of correlation. Although redd densities were low at some sites where habitat conditions were good, i.e., upstream areas with high D.O. and few fines, redd densities were always low at sites where habitat conditions were poor, i.e., downstream areas with low D.O. and high percentages of fines. Therefore, escapement was probably not high enough to utilize all the areas with suitable habitat and the importance of location, intragravel D.O., and percent fines are probably important to chinook salmon in the selection of their spawning habitat.

The relationship between redd density and streambed gradient was not linear and so gradient was not included in the regression. The highest density of redds occurred where the streambed gradient ranged between 0 and 5% (Figure 10). Very steep tails of pools, where the gradient exceeded 5%, are usually locations where scour rates are high and the resulting substrate is coarse. Where the gradient was negative, seen in riffles where the streambed falls in a downstream direction, intragravel D.O. was frequently below 8 ppm. Low D.O. concentrations occur where the streambed is falling in a downstream direction presumably because there is no downwelling of oxygen-rich surface flows. Moreover, D.O. declines as the water passes through substrate containing decaying organic matter as it flows from the riffle crest to its downstream end.

The weak correlations (Tables 7, 8, and 9) with substrate permeability and VHG measured in fall 1998 with all three indices of redd density are probably real although unexpected. It was surprising that salmon did not prefer sites with high permeability (Figure 11) since those sites had relatively loose gravel and fewer fines which would facilitate redd construction. However, salmon greatly increase permeability during redd construction and so the permeability of undisturbed gravel may not be important for redd site selection. The relationship between VHG measured in fall 1998 and redd densities indicates that salmon did not select sites based on downwelling or upwelling over the range of VHG of 0 to 0.25 that was observed during spawning. Perhaps the negative VHG or downwelling that typically occurs at the tails of pools in other rivers is not an important cue for redd site selection.

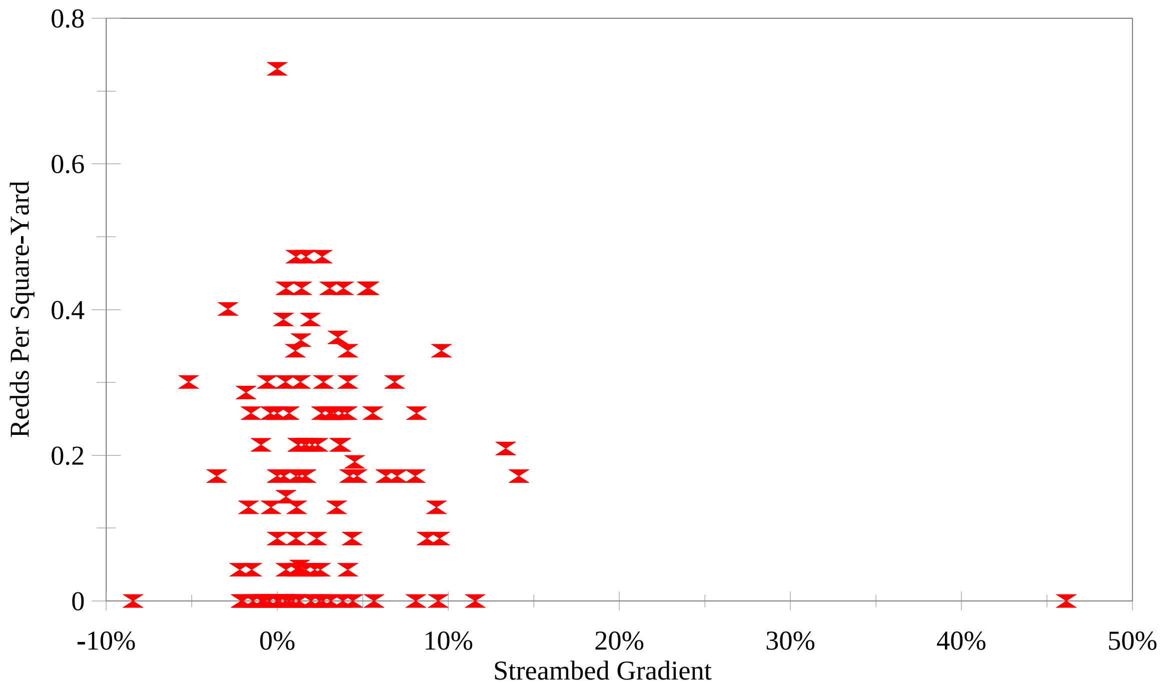

Figure 10. Redd density within a 20-foot radius around standpipe locations in fall 1998 relative to the streambed gradient 10 to 30 feet upstream from standpipes measured in August 1999 in the Stanislaus River.

The weak correlation (*adj*-R^2 = 0.125) between redd density for the entire riffle and surface D.O. concentrations measured in late November 1998 was not surprising. First, most salmon probably selected their spawning habitat in late October and early November when the distribution of surface D.O. may have been different from the late November measurements. In addition, the fall 1998 measurements at the riffles were not made simultaneously but were made throughout the day and over several days. Therefore, they were probably affected by changes in barometric pressure and water temperature and so may not reflect the true distribution of surface D.O. at the study riffles. To properly evaluate the relation between spawning site selection and surface D.O. concentration, it may be necessary to determine the peak of the spawning migration and then simultaneously measure D.O. at several sites within the spawning reach during the migration peak.

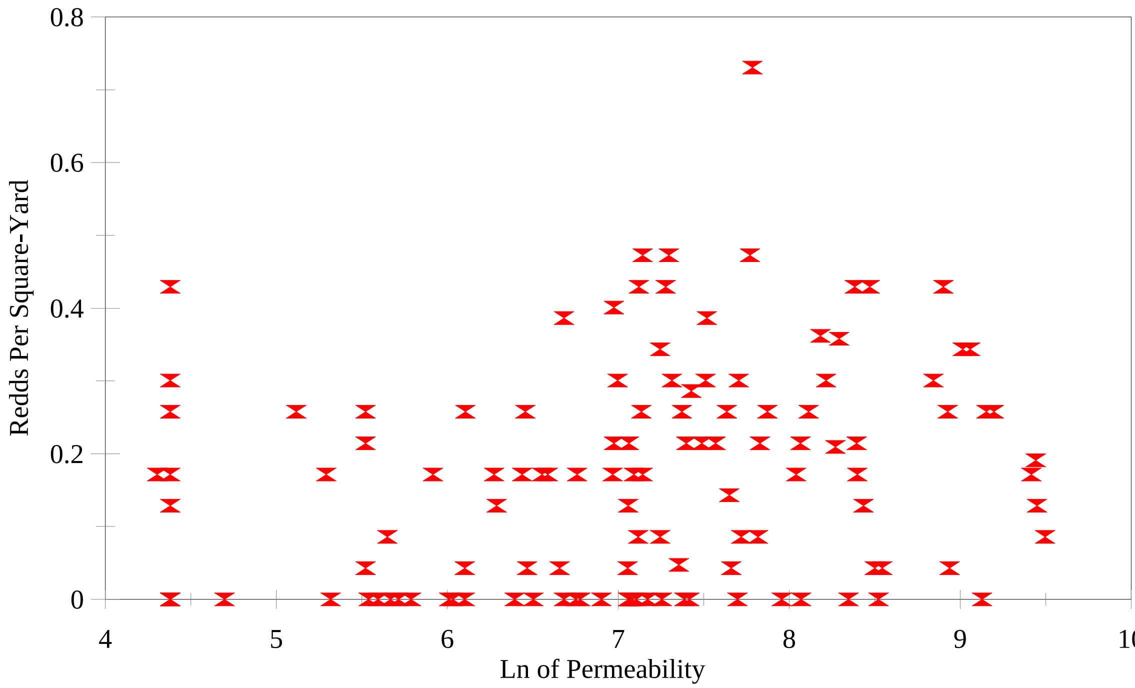

Figure 11. Redd density within a 20-foot radius around standpipe locations in fall 1998 relative to the natural log of the streambed permeability measured at standpipes in August 1999 in the Stanislaus River.

Habitat Features

Stepwise linear regressions were tested for D.O., the natural log of permeability, the percentage of substrate particles finer than 1 mm in the subsurface sample, and VHG with the other habitat variables (Tables 10 through 13 in Appendix 2).

The percentage of particles finer than 1 mm in the subsurface sample explained 20.6% of the variation (*adj-*R^2) in D.O. levels measured in fall 1998 (Figure 12, Table 10), but only 11.4% of the variation in the D.O. levels measured in August 1999 (Figure 13, Table 10). Streambed gradient was positively correlated with D.O. measured in August 1999, although it was not significant (P = 0.072) and there was no correlation with D.O. measured in fall 1998 (P = 0.90). None of the other habitat variables were significantly correlated ($P \geq 0.26$) with D.O.

The percent of particles finer than 1 mm in the subsurface sample explained 23.3% of the variation in the natural log of permeability (Table 11). None of the other habitat variables were significantly correlated ($P \geq 0.34$) with permeability. The percent of particles finer than 1 mm in subsurface samples collected from the Garcia River, Mendocino County, California explained 18.4% of the variation in the natural log of permeability (McBain and Trush 1999).

The percentage of particles finer than 1 mm in the subsurface sample was positively correlated with distance downstream from Goodwin Dam and negatively correlated with both D.O.

measured in August 1999 and the natural log of permeability. The *adj*-R^2 for this regression is 0.317 and $P \leq 0.05$ for all three variables (Table 12). The percent finer than 1 mm was also significantly correlated with the D.O. measured in fall 1998 and the natural log of permeability, but the distance below Goodwin Dam was dropped from this model (Table 12).

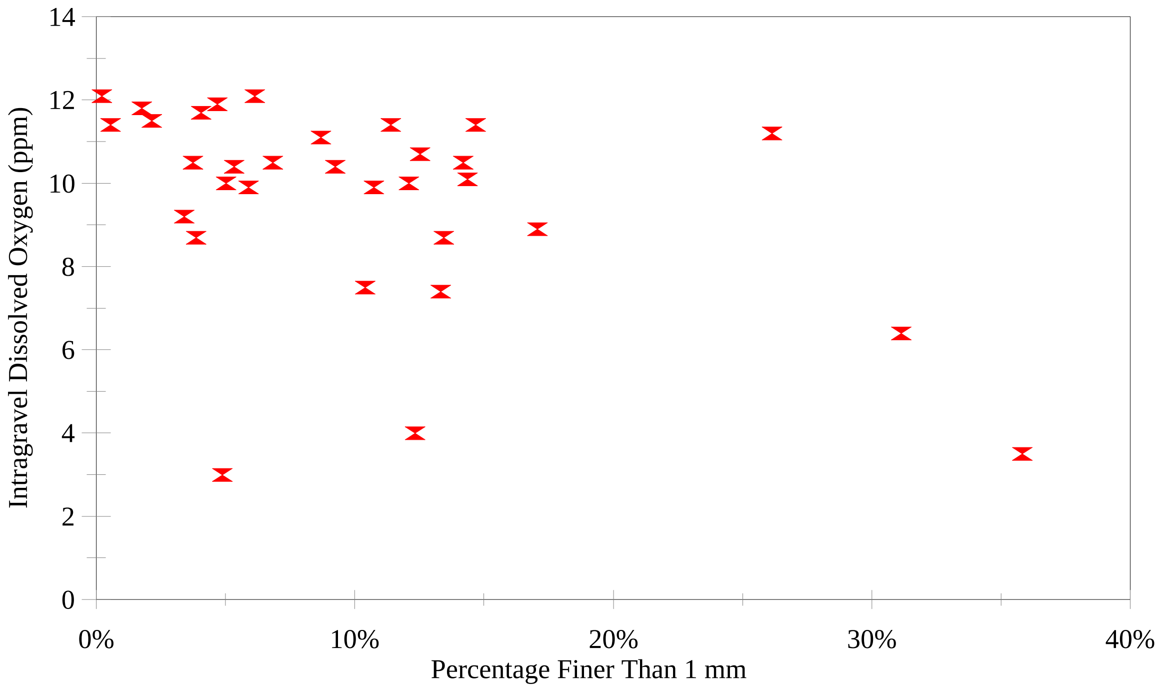

Figure 12. Intragravel dissolved oxygen concentration in fall 1998 relative to the percentage of substrate particles finer than 1 mm in subsurface layer of bulk samples measured at the same standpipe location in August 1999 in the Stanislaus River.

The VHG measured in fall 1998 and August 1999 were not significantly correlated ($P \geq 0.073$) with any of the habitat variables (Table 13). In fall 1998, negative VHG typically occurred where the streambed gradient was near zero, whereas positive VHG was measured where the streambed gradient was both positive and negative (Figure 4).

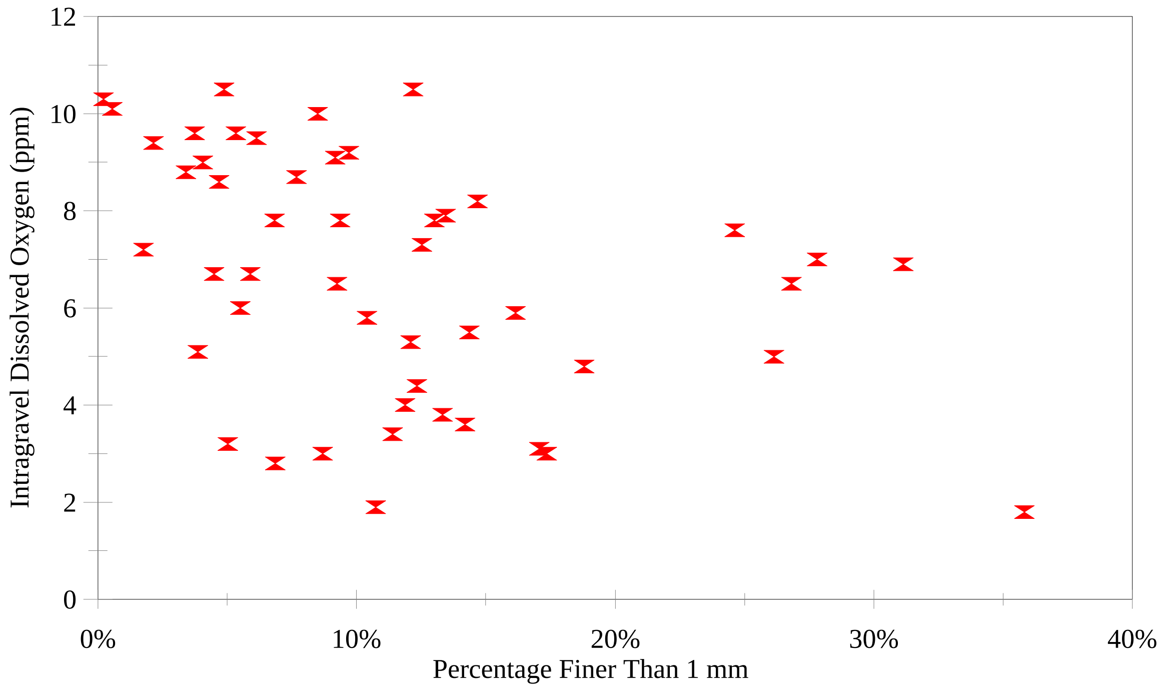

Figure 13. Intragravel dissolved oxygen concentration in August 1999 relative to the percentage of substrate particles finer than 1 mm in subsurface layer of bulk samples measured at the same standpipe location in August 1999 in the Stanislaus River.

DISCUSSION

The pre-project monitoring conducted in fall 1998 and August 1999 adequately documented the distribution of chinook salmon redds within and between the 25 KFGRP riffles. The escapement to the Stanislaus River in fall 1998 was relatively high compared to prior escapements in the 1990s, resulting in spawning habitat that was probably well used although not saturated. In addition, the contour maps produced with a total station provide the exact location of the redds and the elevation of the streambed relative to the areas where restoration gravel was placed in August and September 1999. These data should be adequate to determine the effects of the restoration gravel on redd density and show the rate that restoration gravel is mobilized from the project sites. A casual inspection of the project riffles in July 2000 suggests that high flows caused a few of the riffles to spread out in a downstream direction in an amoeba-like manner. Therefore, the total station measurements should be adequate to document the transport of restoration gravel in the Stanislaus River.

The condition of the undisturbed streambed in terms of intragravel dissolved oxygen concentration, permeability, substrate composition, and vertical hydraulic gradient (VHG; i.e., upwelling versus downwelling), was also well documented before gravel was added. These data should be adequate to determine the longevity of the restoration riffles for spawning habitat before the substrate pores become filled with fine sediments and decomposing organic matter. The permeability measurements should be particularly useful for determining the rate of fine sediment intrusion. Although there was substantial variation in the permeability within some of the study riffles, the permeability at the project sites where the restoration gravel was at least 18 inches deep in October 1999 ranged between 83,563 and 299,040 cm/hr (mean of 172,631 cm/hr), which was at least 6 times higher than the highest measurement made of the pre-project conditions in August 1999. Therefore, it is likely that the data will be adequate to show that the differences are statistically different.

The data were also useful for characterizing redd site selection by chinook salmon in the Stanislaus River. Most salmon appear to swim upstream until they reach a cue, possibly a high surface D.O. concentration, before they select a spawning site. At that point most salmon then select a spawning site in a riffle where the gradient ranges between 0 and 5%, intragravel D.O. is high, and the percentages of substrate particles finer than 1 mm are low. Redd site selection was unrelated to permeability, median size of the surface substrate particles, or vertical hydraulic gradient in the Stanislaus River. Comparisons of redd density between project sites and control sites for the fall 1999 and fall 2000 surveys will have to consider the influence that distance below Goodwin Dam has on redd density. Furthermore, the timing of the salmon migration and surface D.O. concentrations may differ between years thereby potentially changing the relationship between redd density and distance below Goodwin Dam. If this occurs, it may not be possible to statistically compare redd densities between years. Instead, comparisons will have to rely solely on comparisons between treatment and control sites within the same year.

It was not possible to investigate the suitability of riffle habitat for incubating eggs in fall 1998 because the flows were too high to install the monitoring equipment. This is an important aspect of this study because chinook salmon and other salmonids create suitable incubation habitat during redd construction by reducing the amount of fines in the substrate and increasing substrate permeability and the downwelling of oxygenated surface water into the egg pocket (Bjornn and Reiser 1991). A primary limitation for spawning habitat in the Stanislaus River is that the salmon must crowd into a few riffles in the upstream reaches whereby redd construction by late-arriving females results in high rates of fine sediment intrusion at redds constructed early in the spawning season or results in mortality when eggs are dug up (Mesick 2001a). In addition, fine sediment intrusion can be high during intense rainstorms and intragravel dissolved oxygen concentrations can be low in areas of the Stanislaus River where permeability is moderate and substrate fines are minimal presumably due to the inflow of oxygen-poor groundwater (Mesick 2001a). If the flows had been lower in fall 1998, incubation conditions would have been measured by constructing artificial redds with minipiezometers and thermographs buried where the egg pocket would be located at the bottom of the redd to periodically collect water samples, measure VHG, and to use intragravel water temperatures as an index of apparent velocity in the redd during most of the incubation period. Disturbances of the minipiezometers also serve as an indication that redd superimposition would have occurred. These methods were used in fall 1996 (Mesick 2001a) to generally document pre-project conditions. These methods were also used during the fall 1999 post-project monitoring for the KFGRP and additional data were collected at unrestored sites. A study of the relationship between intragravel water temperatures, permeability, apparent velocity, and dissolved oxygen within the artificial redds will be made in fall 2000 to help compare expected egg survival rates in the control sites versus the project sites.

Measures of apparent velocity are preferred over permeability measurements at artificial redds because the high rates of pumping required to measure permeability removes a substantial amount of fine sediment from the substrate which potentially increases permeability during subsequent periodic monitoring. McBain and Trush (1999) repeatedly measured permeability at standpipes and observed that permeability increased by about 20% as successive measurements were taken at some standpipes. Furthermore, driving the standpipe into the substrate also disrupts the layers of fine sediments that may accumulate and form a seal over time (Beschta and Jackson 1979) thereby affecting dissolved oxygen concentrations and permeability. On the other hand, apparent velocity measurements are time consuming and require specialized equipment (Wickett 1954, Pollard 1955, Gangmark and Bakkala 1958, Terhune 1958, Clayton and others 1996), whereas permeability measurements are relatively simple and quick making it possible to collect numerous samples needed to characterize entire riffles, which tend to be heterogeneous (Barnard and McBain 1994, McBain and Trush 1999). Other measures of incubation habitat, such as using egg incubation chambers, redd caps, or sampling the substrates in redds after incubation, would be very difficult to use in the Stanislaus River because flood control releases typically begin in early February, which is before most of the alevins are ready to emerge. Region 4 of the Department of Fish and Game has also been reluctant to allow measurements to be taken in a substantial number of actual redds while the eggs are incubating.

Monitoring at the DFG restoration site in upper Goodwin Canyon, DFG2, indicated that redd densities were about three times higher than those at nearby KFGRP riffles TMA and TM1. In addition, intragravel D.O. concentrations averaged 99% of saturation levels and upwelling flows were relatively strong within the riffle. Since there was insufficient gravel for spawning at this site prior to gravel introduction in 1997, the high redd densities and D.O. levels indicate that the restoration was initially successful.

ACKNOWLEDGMENTS

I am indebted to Mr. Sean Smith, the construction supervisor, for volunteering to help measure streambed elevations in November 1998. I thank Darren Mierau of McBain and Trush for assisting with the construction of the permeability pump and standpipes and providing instructions for their use. I also thank the landowners, Ms. Nancy Frymire, Mr. Gordon Crawford, and Mr. and Mrs. Robert Hunter, who provided access to some of the study sites. I thank Messrs. Dan Castleberry and Marty Kjelson, my ex-supervisors at the U.S. Fish and Wildlife Service, for being patient with me while I completed this task and simultaneously performed my duties for the Anadromous Fish Restoration Program. I greatly appreciate the assistance provided by Mr. Phillip Holcomb, Ms. Peggi Brooks, and Mr. Jason Anderson with the Stanislaus River Parks, U.S. Army Corps of Engineers in Knights Ferry. This task was jointly funded by the CALFED Bay Delta Program and the Stockton East Water District.

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APPENDIX 1

USGS QUADRANGLES SHOWING SITE LOCATIONS

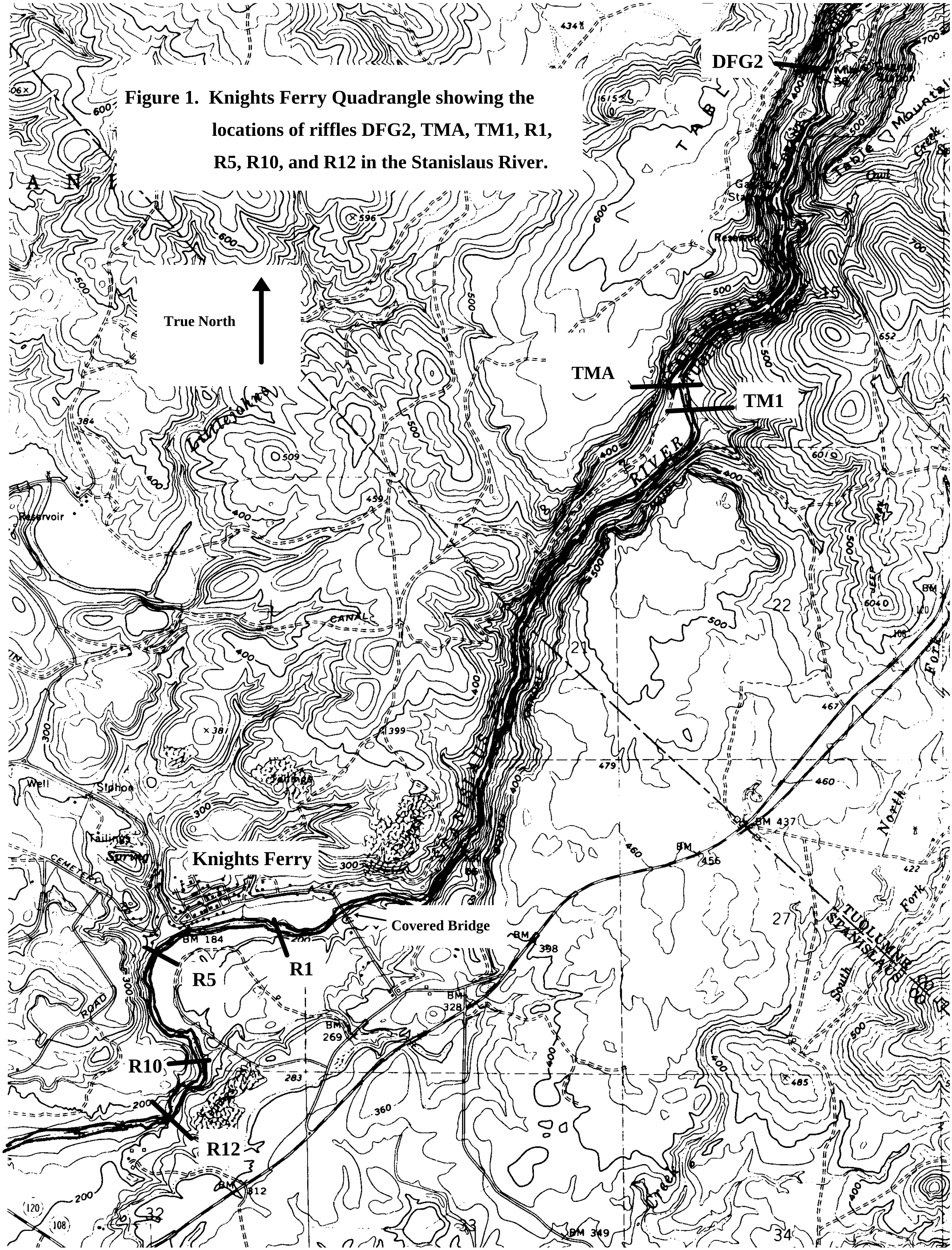


Figure 1. Knights Ferry Quadrangle showing the locations of riffles DFG2, TMA, TM1, R1, R5, R10, and R12 in the Stanislaus River.

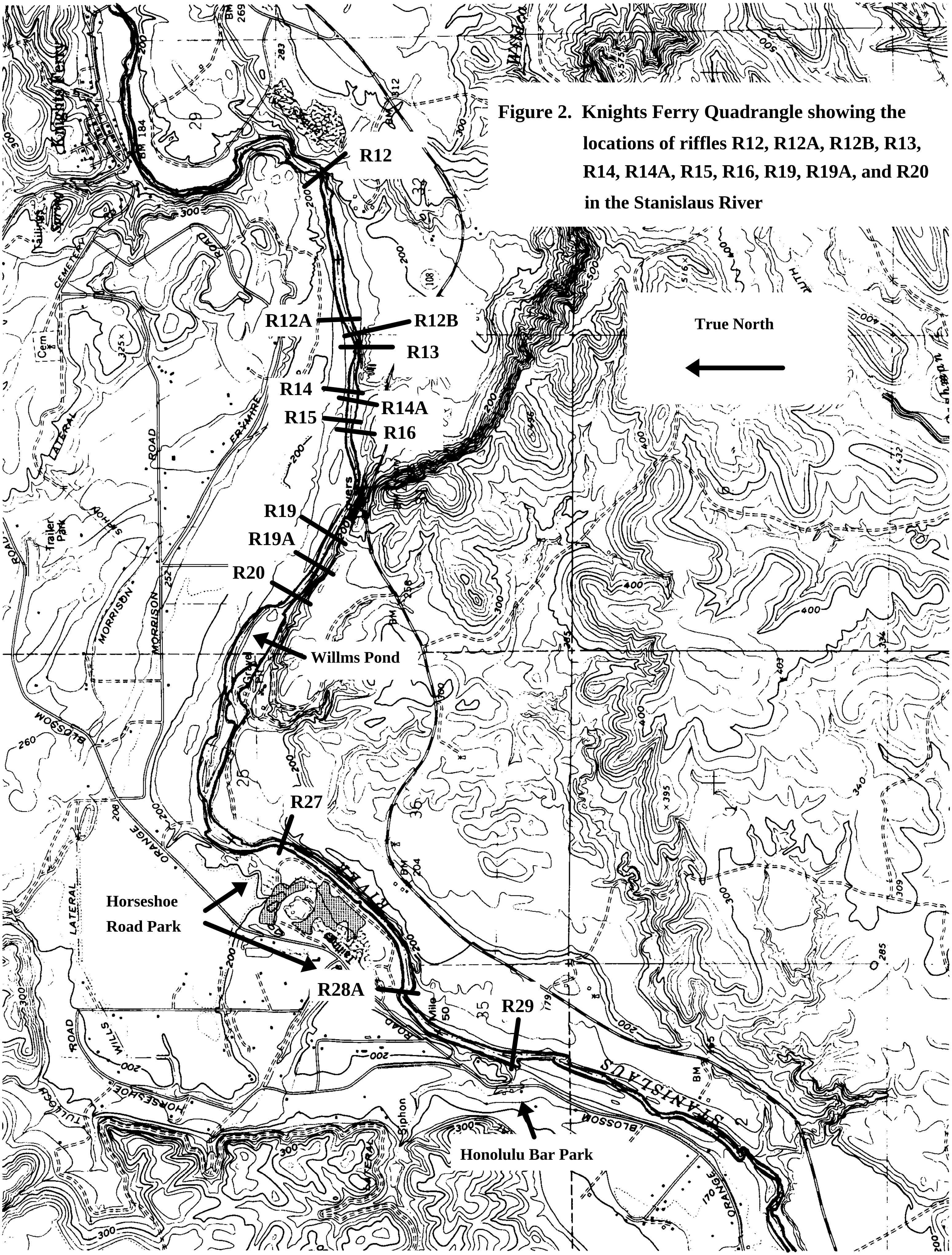


Figure 2. Knights Ferry Quadrangle showing the locations of riffles R12, R12A, R12B, R13, R14, R14A, R15, R16, R19, R19A, and R20 in the Stanislaus River

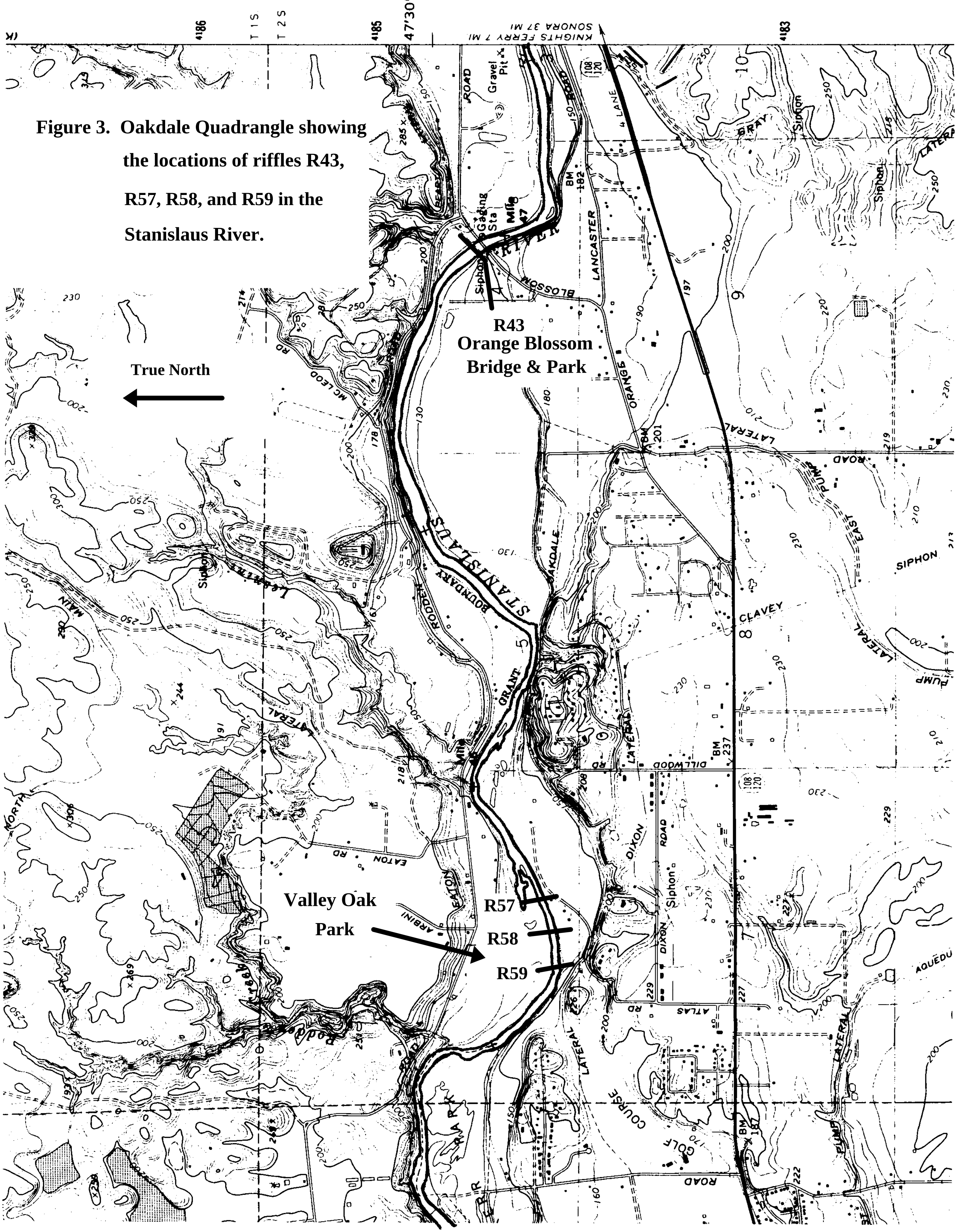
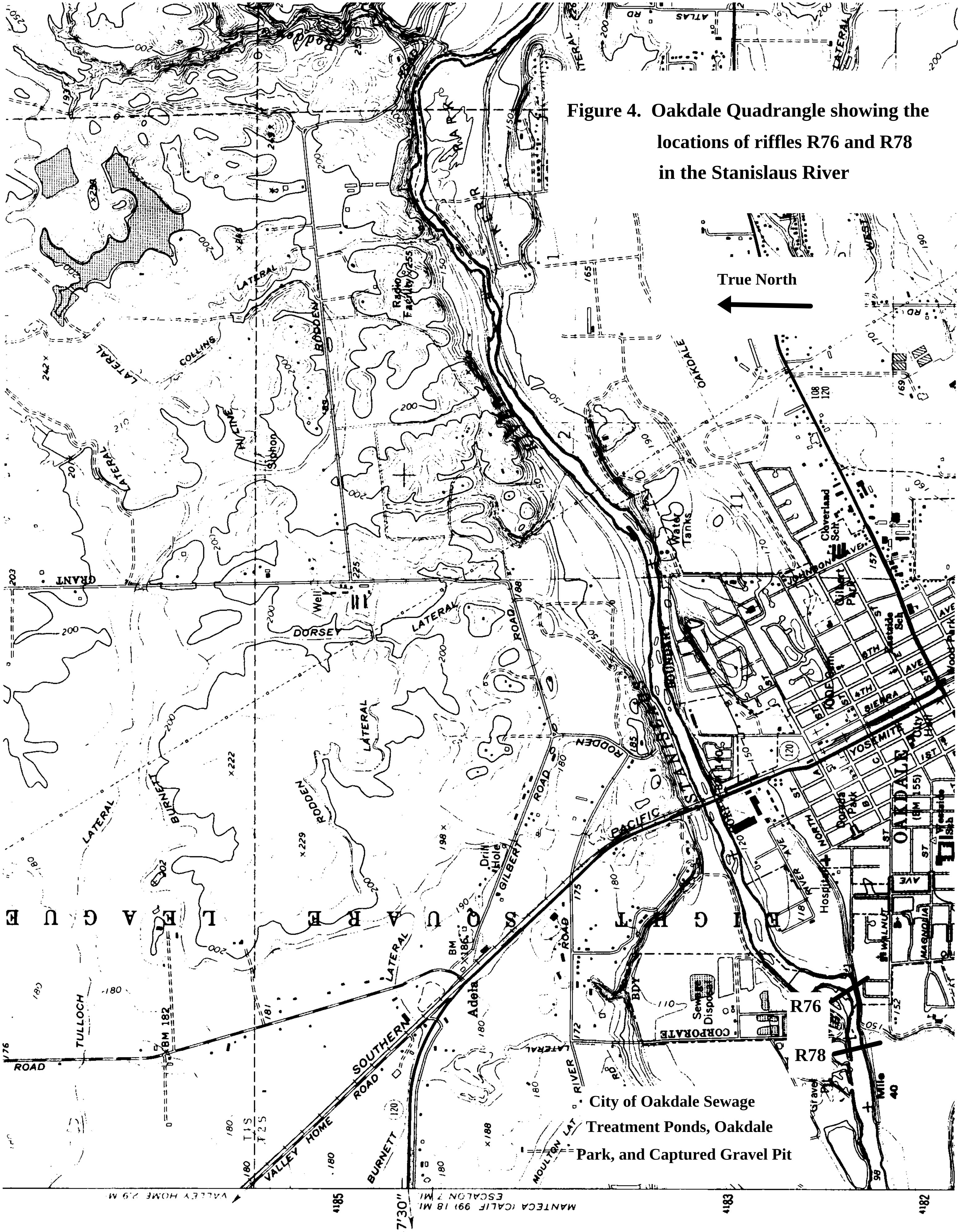


Figure 3. Oakdale Quadrangle showing the locations of riffles R43, R57, R58, and R59 in the Stanislaus River.

Figure 4. Oakdale Quadrangle showing the locations of riffles R76 and R78 in the Stanislaus River



APPENDIX 2

Tables 1-13 of Results

Table 1. The rivermile and streambed gradient upstream from the riffle's crest of the riffles selected for the,Knights Ferry Gravel Replenishment Project in the Stanislaus River and the amount of gravel placed at the 18 project riffles in August and September 1999. The seven control riffles were not altered.

A) High-Crested Riffles (Tails of Deep Pools), 3.4% to 17.7% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
TMA	56.8	Stanislaus River-Rock, 1/4 to 5 inch diameter	840	470	6.9%
TM1	56.6	Control Riffle, No Gravel Added	--	--	4.3%
R1	54.55	Stanislaus River-Rock, 3/8 to 5 inch diameter	550	395	10.5%
R12	53.3	Control Riffle, No Gravel Added	--	--	3.4%
R14A	52.57	Stanislaus River-Rock, 3/8 to 5 inch diameter	1,430	1,055	5.4%
R28A	50.2	Stanislaus River-Rock, 1/4 to 5 inch diameter	450	250	5.2%
R29	49.75	Tuolumne River-Rock, 3/8 to 5 inch diameter	300	210	4.7%
R76	40.35	Control Riffle, No Gravel Added	--	--	17.7%
B) Moderate-Crested Riffles, 1.6 to 3% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
R13	52.73	Stanislaus River-Rock, 3/8 to 5 inch diameter	1,200	860	1.7%
R15	52.51	Tuolumne River-Rock, 3/8 to 5 inch diameter	860	610	2.4%
R16	52.48	Tuolumne River-Rock, 3/8 to 5 inch diameter	330	240	2.8%
R20	51.8	Control Riffle, No Gravel Added	--	--	1.6%
R27	50.8	Control Riffle, No Gravel Added	--	--	2.9%
R43	46.9	Tuolumne River-Rock, 3/8 to 5 inch diameter	440	315	2.0%
R58	44.5	Stanislaus River-Rock, 1/4 to 5 inch diameter	840	465	3.0%
R78	40.2	Tuolumne River-Rock, 3/8 to 5 inch diameter	570	405	2.5%
C) Low-Crested Riffles, 0 to 1.5% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
R5	53.9	Tuolumne River-Rock, 3/8 to 5 inch diameter	440	315	-0.4%
R10	53.5	Control Riffle, No Gravel Added	--	--	0.5%
R12A	52.82	Stanislaus River-Rock, 3/8 to 5 inch diameter	540	380	0.9%
R12B	52.77	Stanislaus River-Rock, 1/4 to 5 inch diameter	850	470	1.5%
R14	52.6	Stanislaus River-Rock, 1/4 to 5 inch diameter	835	465	1.3%
R19	52.13	Stanislaus River-Rock, 1/4 to 5 inch diameter	675	130	0.6%
R19A	52.06	Stanislaus River-Rock, 3/8 to 5 inch diameter	950	680	0.5%
R57	44.6	Stanislaus River-Rock, 3/8 to 5 inch diameter	900	645	0.1%
R59	44.4	Control Riffle, No Gravel Added	--	--	-0.5%

Table 2. Table for converting field inflow rate (ml/s) measurements in 0.1 increments to permeability (cm/hr).

(ml/s)	**0.0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
2	80	110	120	150	160	170	175	180	185	190
3	195	210	220	230	240	250	260	270	280	285
4	290	305	310	320	330	340	350	360	370	380
5	390	405	415	430	440	450	465	475	485	490
6	500	505	515	530	540	550	565	575	585	590
7	600	605	615	630	640	650	665	675	685	690
8	705	710	720	730	740	750	765	785	795	800
9	810	815	825	835	845	850	860	870	880	885
10	890	905	920	935	950	960	970	980	990	1000
11	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190
12	1200	1210	1220	1230	1240	1250	1260	1270	1280	1290
13	1300	1310	1320	1330	1340	1350	1360	1370	1380	1390
14	1400	1410	1420	1430	1440	1450	1460	1470	1480	1490
15	1500	1510	1520	1530	1540	1550	1560	1570	1580	1590
16	1600	1610	1620	1630	1640	1650	1660	1670	1680	1690
17	1700	1710	1720	1730	1740	1750	1760	1770	1780	1790
18	1800	1810	1820	1830	1840	1850	1860	1870	1880	1890
19	1900	1915	1930	1940	1950	1960	1970	1980	1990	2000
20	2020	2070	2100	2120	2140	2150	2160	2170	2180	2190
21	2200	2210	2220	2230	2240	2250	2260	2270	2280	2290
22	2300	2310	2320	2330	2340	2350	2360	2370	2380	2390
23	2400	2410	2420	2430	2440	2450	2460	2470	2480	2490
24	2500	2510	2520	2530	2540	2550	2560	2570	2580	2590
25	2600	2610	2620	2630	2640	2650	2660	2670	2680	2690
26	2700	2710	2720	2730	2740	2750	2760	2770	2780	2790
27	2800	2810	2820	2830	2840	2850	2860	2870	2880	2890
28	2900	2910	2920	2930	2940	2950	2960	2970	2980	2990
29	3000	3010	3020	3030	3040	3050	3060	3070	3080	3090
30	3100	3120	3140	3160	3180	3200	3220	3240	3260	3280
31	3300	3340	3380	3420	3450	3480	3510	3540	3560	3580
32	3600	3620	3640	3660	3680	3700	3720	3740	3760	3780
33	3800	3820	3840	3860	3880	3900	3920	3940	3960	3980
34	4000	4020	4040	4060	4080	4100	4120	4140	4160	4180
35	4200	4220	4240	4260	4280	4300	4320	4340	4360	4380
36	4400	4420	4440	4460	4480	4500	4520	4540	4560	4580
37	4600	4610	4620	4630	4640	4650	4660	4670	4680	4690
38	4700	4710	4720	4730	4740	4750	4760	4770	4780	4790
39	4800	4810	4820	4830	4840	4850	4860	4870	4880	4890
40	4900	4910	4920	4930	4940	4950	4960	4970	4980	4990

Table 2 (Continued)

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
41	5100	5120	5140	5160	5180	5200	5220	5240	5260	5280
42	5300	5320	5340	5360	5380	5400	5420	5440	5460	5480
43	5400	5420	5440	5460	5480	5500	5520	5540	5560	5580
44	5500	5520	5540	5560	5580	5600	5620	5640	5660	5680
45	5600	5620	5640	5660	5680	5700	5720	5740	5760	5780
46	5700	5720	5740	5760	5780	5800	5820	5840	5860	5880
47	5800	5820	5840	5860	5880	5900	5920	5940	5960	5980
48	6000	6050	6100	6140	6180	6220	6260	6300	6340	6380
49	6400	6450	6500	6540	6580	6620	6660	6700	6740	6780
50	6800	6830	6860	6890	6920	6950	6980	7010	7040	7070
51	7100	7130	7160	7190	7220	7250	7280	7310	7340	7370
52	7400	7450	7500	7540	7580	7620	7660	7700	7740	7780
53	7800	7850	7900	7940	7980	8020	8060	8100	8140	8181
54	8200	8250	8300	8340	8380	8420	8460	8500	8540	8580
55	8600	8650	8700	8740	8780	8820	8860	8900	8940	8980
56	9000	9050	9100	9140	9180	9220	9260	9300	9340	9380
57	9400	9430	9460	9490	9520	9550	9580	9610	9640	9670
58	9700	9730	9760	9790	9820	9850	9880	9910	9940	9970
59	10000	10030	10060	10090	10120	10150	10180	10210	10240	10270
60	10300	10350	10400	10440	10480	10520	10560	10600	10640	10680
61	10700	10730	10760	10790	10820	10850	10880	10910	10940	10970
62	11000	11030	11060	11090	11120	11150	11180	11210	11240	11270
63	11300	11330	11360	11390	11420	11450	11480	11510	11540	11570
64	11600	11650	11700	11740	11780	11820	11860	11900	11940	11980
65	12000	12050	12100	12140	12180	12220	12260	12300	12340	12380
66	12400	12450	12500	12540	12580	12620	12660	12700	12740	12780
67	12800	12850	12900	12940	12980	13020	13060	13100	13140	13180
68	13200	13250	13300	13340	13380	13420	13460	13500	13540	13580
69	13600	13650	13700	13740	13780	13820	13860	13900	13940	13980
70	14000	14060	14120	14180	14240	14300	14360	14420	14480	14540
71	14600	14660	14720	14780	14840	14900	14960	15020	15080	15140
72	15200	15270	15340	15410	15480	15550	15620	15690	15760	15830
73	15900	15970	16140	16110	16180	16250	16320	16390	16460	16530
74	16600	16670	16740	16810	16880	16950	17020	17090	17160	17230
75	17300	17370	17440	17510	17580	17650	17720	17790	17860	17930
76	18000	18070	18140	18210	18280	18350	18420	18490	18560	18630
77	18700	18770	18840	18910	18980	19050	19120	19190	19260	19330
78	19400	19480	19560	19640	19720	19800	19880	19960	20040	20120

Table 2 (Continued)

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
79	20200	20280	20360	20440	20520	20600	20680	20760	20840	20920
80	21000	21200	21400	21600	21800	22000	22200	22400	22600	22800
81	23000	23150	23300	23450	23600	23750	23900	24050	24200	24350
82	24500	24650	24800	24950	25100	25250	25400	25550	25700	25850
83	26000	26100	26200	26300	26400	26500	26600	26700	26800	26900
84	27000	27100	27200	27300	27400	27500	27600	27700	27800	27900
85	28000	28100	28200	28300	28400	28500	28600	28700	28800	28900
86	29000	29100	29200	29300	29400	29500	29600	29700	29800	29900
87	30000	30100	30200	30300	30400	30500	30600	30700	30800	30900
88	31000	31100	31200	31300	31400	31500	31600	31700	31800	31900
89	32000	32100	32200	32300	32400	32500	32600	32700	32800	32900
90	33000	33300	33600	33900	34200	34500	34800	35100	35400	35700
91	36000	36300	36600	36900	37200	37500	37800	38100	38400	38700
92	39000	39100	39200	39300	39400	39500	39600	39700	39800	39900
93	40000	40100	40200	40300	40400	40500	40600	40700	40800	40900
94	41000	41100	41200	41300	41400	41500	41600	41700	41800	41900
95	42000	42100	42200	42300	42400	42500	42600	42700	42800	42900
96	43000	43100	43200	43300	43400	43500	43600	43700	43800	43900
97	44000	44100	44200	44300	44400	44500	44600	44700	44800	44900
98	45000	45100	45200	45300	45400	45500	45600	45700	45800	45900
99	46000	46100	46200	46300	46400	46500	46600	46700	46800	46900
100	47000	47500	48000	48500	49000	49500	50000	50500	51000	51500
101	52000	52600	53200	53800	54400	55000	55600	56200	56800	57400
102	58000	58600	59200	59800	60400	61000	61600	62200	62800	63400
103	64000	64600	65200	65800	66400	67000	67600	68200	68800	69400
104	70000	70500	71000	71500	72000	72500	73000	73500	74000	74500
105	75000	75500	76000	76500	77000	77500	78000	78500	79000	79500
106	80000	80500	81000	81500	82000	82500	83000	83500	84000	84500
107	85000	85500	86000	86500	87000	87500	88000	88500	89000	89500
108	90000	90500	91000	91500	92000	92500	93000	93500	94000	94500
109	95000	95500	96000	96500	97000	97500	98000	98500	99000	99500
110	100000	100500	101000	101500	102000	102500	103000	103500	104000	104500

Table 3 The number of redds, riffle area, density of redds, and distance below Goodwin Dam for the 25 KFGRP riffles in the Stanislaus River. The project riffles were segregated into two areas. One area is where gravel was placed in fall 1999 and is referred to as "inside" in the table's subheading below. The other area was immediately adjacent to where the gravel was added and is referred to as "outside" in the table's subheading below.

Site	Number of Redds		Riffle Area (square-yards)		Redds/yd^2			Location
	Inside	Outside	Inside	Outside	Inside	Outside	Entire Riffle	Miles Below Goodwin Dam
TMA	23	12	249	118	0.092	0.102	0.095	1.70
TM1*	--	47	--	403	--	--	0.117	1.90
R1	44	13	277	70	0.159	0.186	0.164	3.95
R5	1	6	176	38	0.006	0.158	0.033	4.60
R10*	--	56	--	412	--	--	0.136	5.00
R12*	--	28	--	165	--	--	0.170	5.20
R12A	3	16	125	217	0.024	0.074	0.056	5.65
R12B	6	15	178	172	0.034	0.087	0.060	5.73
R13	0	0	357	--	0.000	--	0.000	5.77
R14	48	12	409	97	0.117	0.124	0.119	5.90
R14A	0	10	200	371	0.000	0.027	0.018	5.93
R15	1	4	201	65	0.005	0.062	0.019	5.99
R16	10	4	186	65	0.054	0.062	0.056	6.02
R19	17	63	282	608	0.060	0.104	0.090	6.37
R19A	0	0	256	--	0.000	--	0.000	6.44
R20*	--	93	--	1302	--	--	0.071	6.70
R27*	--	21	--	280	--	--	0.075	7.70
R28A	17	4	128	35	0.132	0.114	0.128	8.30
R29	16	2	103	96	0.156	0.021	0.090	8.75
R43	2	19	139	277	0.014	0.069	0.051	11.60
R57	0	0	186	--	0.000	--	0.000	13.90
R58	3	0	393	13	0.008	0.000	0.007	14.00
R59*	--	3	--	379	--	--	0.008	14.10
R76*	--	0	--	165	--	--	0.000	18.15
R78	1	0	277	190	0.004	0.000	0.002	18.30
Total	192	428	--	--	--	--	--	--
Average	--	--	229	252	0.048	0.079	0.063	--

* control sites

Table 4. The permeability, density of redds measured in both a 10-foot and a 20-foot radius about the standpipe locations, intragravel dissolved oxygen concentration measured in fall 1998 and August 1999, vertical hydraulic gradient (VHG) measured in fall 1998 and August 1999, gradient of the streambed upstream of the standpipe location for a distance of 10 to 30 feet, and miles below Goodwin Dam for 77 standpipe samples in fall 1998 and 123 standpipe samples in August 1999 at the 25 Knights Ferry Gravel Replenishment Project riffles in the Stanislaus River.

Riffle Standpipe	Permeability Aug 99 (cm/hr)	Redds Per Square-Yd (20-ft radius)	Redds Per Square-Yd (10-ft radius)	D.O. Fall 98 (ppm)	D.O. Fall 98 Percent Saturation	D.O. Aug 99 (ppm)	D.O. Aug 99 Percent Saturation	VHG Fall 98	VHG 08/99	Gradient	Miles below Goodwin Dam
TMA P1	1306	0.00	0.00	--	--	5.9	53.2%	--	-0.100	11.59%	1.7
TMA P2	1205	0.17	0.52	11.7	95.9%	9.0	81.1%	0.083	-0.093	14.15%	1.7
TMA P3	2070	0.26	0.69	10.1	82.8%	9.3	83.8%	0.083	-0.150	8.16%	1.7
TMA P4	4931	0.04	0.00	11.4	93.4%	10.1	91.0%	0.533	-0.103	2.53%	1.7
TMA P5	704	0.17	0.52	9.7	79.5%	9.7	87.4%	0.183	-0.117	1.68%	1.7
TM1 P1	3584	0.36	0.69	9.5	77.9%	7.9	74.5%	-0.017	0.027	3.57%	1.9
TM1 P2	4425	0.21	0.00	10.5	86.1%	9.7	91.5%	0.000	0.027	2.07%	1.9
TM1 P3	2371	0.47	0.86	--	--	9.2	86.8%	--	0.007	2.63%	1.9
TM1 P4	2516	0.21	0.17	11.5	94.3%	8.0	75.5%	0.033	0.033	1.58%	1.9
TM1 P5	199	0.17	0.34	10.0	82.0%	3.2	30.2%	0.080	-0.027	4.27%	1.9
TM1 P6	638	0.26	0.34	11.5	94.3%	9.4	88.7%	0.090	-0.047	5.59%	1.9
R1 P1	2257	0.09	0.17	--	--	8.3	72.8%	--	-0.070	9.49%	3.95
R1 P2	1165	0.13	0.17	--	--	9.2	80.7%	--	0.073	3.47%	3.95
R1 P3	2220	0.30	0.69	9.2	77.3%	8.8	77.2%	0.043	-0.107	4.14%	3.95
R1 P4	1238	0.43	0.52	10.5	88.2%	9.6	86.5%	0.100	0.000	5.26%	3.95
R1 P5	2412	0.73	0.86	11.9	100.0%	8.6	75.4%	0.100	0.073	0.00%	3.95
R1 P6	1265	0.47	1.03	10.0	84.0%	9.2	80.7%	0.200	0.077	1.10%	3.95
R5 P1	304	0.00	0.00	10.7	85.6%	7.3	67.0%	0.033	-0.150	0.00%	4.6
R5 P2	1095	0.30	1.03	8.7	69.6%	7.9	72.5%	0.017	-0.033	-0.56%	4.6
R5 P3	74	0.17	0.34	--	--	2.5	22.9%	--	-0.050	7.03%	4.6
R10 P1	7631	0.04	0.00	--	--	9.9	92.5%	--	-0.013	0.54%	5

Table 4 (Continued)

Riffle Standpipe	Permeability Aug 99 (cm/hr)	Redds Per Square-Yd (20-ft radius)	Redds Per Square-Yd (10-ft radius)	D.O. Fall 98 (ppm)	D.O. Fall 98 Percent Saturation	D.O. Aug 99 (ppm)	D.O. Aug 99 Percent Saturation	VHG Fall 98	VHG 08/99	Gradient	Miles below Goodwin Dam
R10 P2	7345	0.43	0.34	11.4	91.2%	8.4	78.5%	0.000	-0.010	3.07%	5
R10 P3	2100	0.14	0.34	9.9	79.2%	1.9	17.8%	0.050	0.013	0.52%	5
R10 P4	1267	0.17	0.17	11.4	91.2%	3.4	31.8%	-0.067	0.017	0.41%	5
R10 P5	3996	0.36	0.34	--	--	2.8	26.2%	--	0.050	1.40%	5
R10 P6	3700	0.30	0.52	10.1	80.8%	6.2	57.9%	0.000	0.000	1.36%	5
R12 P1	12609	0.19	0.38	--	--	9.2	87.6%	--	0.033	4.55%	5.2
R12 P2	3916	0.21	0.21	10.8	90.8%	8.4	80.0%	0.233	0.020	13.38%	5.2
R12 P3	727	0.17	0.38	--	--	8.7	82.9%	--	-0.027	0.00%	5.2
R12 P4	1638	0.21	0.34	9.0	75.6%	6.0	57.1%	0.250	0.000	1.27%	5.2
R12 P5	1071	0.40	0.95	11.1	93.3%	3.0	28.6%	0.233	0.033	-2.86%	5.2
R12 P6	1830	0.30	0.34	7.2	60.5%	1.9	18.1%	0.150	0.030	-5.17%	5.2
R12A P1	5142	0.04	0.00	10.6	86.2%	3.5	31.3%	0.050	-0.050	--	5.65
R12A P2	1071	0.21	0.17	10.0	81.3%	5.3	47.3%	0.033	-0.017	1.75%	5.65
R12A P3	13359	0.09	0.00	9.4	76.4%	6.2	55.4%	0.033	0.000	0.00%	5.65
R12A P4	9873	0.26	0.69	--	--	8.1	72.3%	--	0.027	3.24%	5.65
R12B P1	12290	0.17	0.17	8.7	70.7%	5.1	44.7%	0.040	-0.027	-3.51%	5.73
R12B P2	2127	0.04	0.17	5.7	46.3%	4.0	35.1%	0.000	-0.020	-2.19%	5.73
R12B P3	9448	0.26	0.34	11.4	92.7%	8.2	71.9%	0.100	0.037	3.83%	5.73
R12B P4	12724	0.13	0.17	11.3	91.9%	9.0	78.9%	0.133	0.040	-0.33%	5.73
R13 P1	110	0.00	0.00	--	--	7.5	68.2%	--	-0.017	3.85%	5.77
R13 P2	9232	0.00	0.00	--	--	8.9	80.9%	--	0.027	--	5.77
R13 P3	80	0.00	0.00	--	--	3.2	29.1%	--	--	--	5.77
R13 P4	80	0.00	0.00	--	--	2.1	19.1%	--	--	--	5.77
R14 P1	4374	0.43	0.69	11.0	90.2%	10.8	94.7%	0.050	-0.043	5.38%	5.9
R14 P2	450	0.26	0.34	10.8	88.5%	9.5	83.3%	0.033	-0.060	-1.52%	5.9
R14 P3	1476	0.47	0.86	11.1	90.2%	9.5	83.3%	0.057	-0.040	1.70%	5.9

Table 4 (Continued)

Riffle Standpipe	Permeability Aug 99 (cm/hr)	Redds Per Square-Yd (20-ft radius)	Redds Per Square-Yd (10-ft radius)	D.O. Fall 98 (ppm)	D.O. Fall 98 Percent Saturation	D.O. Aug 99 (ppm)	D.O. Aug 99 Percent Saturation	VHG Fall 98	VHG 08/99	Gradient	Miles below Goodwin Dam
R14 P4	4788	0.43	0.34	--	--	7.8	17.6%	--	-0.030	1.44%	5.9
R14 P5	1404	0.34	0.57	--	--	10.6	93.0%	--	0.027	4.14%	5.9
R14 P6	1683	0.29	0.38	11.1	93.4%	10.5	92.1%	0.433	0.033	-1.80%	5.9
R14A P1	1162	0.04	0.17	3.3	27.0%	6.2	54.4%	0.167	-0.040	4.13%	5.93
R14A P2	1940	0.21	0.34	--	--	4.8	42.1%	--	0.060	1.22%	5.93
R14A P3	1171	0.21	0.17	1.8	14.8%	4.8	42.1%	0.150	0.127	2.39%	5.93
R14A P4	448	0.04	0.00	--	--	8.4	73.7%	--	-0.037	1.15%	5.93
R15 P1	645	0.04	0.17	--	--	4.5	42.5%	--	0.020	-1.47%	5.99
R15 P2	80	0.17	0.34	11.2	92.6%	5.0	47.2%	0.058	-0.037	8.09%	5.99
R15 P3	2489	0.09	0.17	10.5	86.8%	7.8	73.6%	0.050	-0.033	2.32%	5.99
R16 P1	1062	0.17	0.00	10.9	90.1%	8.8	77.2%	0.133	0.033	1.62%	6.02
R16 P2	2628	0.26	0.34	10.7	88.4%	9.0	78.9%	0.017	0.017	3.05%	6.02
R16 P3	1791	0.21	0.69	--	--	9.1	79.8%	--	0.007	3.67%	6.02
R16 P4	599	0.00	0.00	8.4	69.4%	6.8	59.6%	0.083	-0.060	2.68%	6.02
R19 P1	3105	0.17	0.17	10.0	84.7%	7.2	65.5%	0.047	0.000	1.12%	6.37
R19 P2	801	0.39	0.34	11.8	100.0%	9.4	85.5%	0.000	-0.010	0.37%	6.37
R19 P3	3186	0.21	0.38	--	--	10.0	90.9%	--	-0.010	-0.93%	6.37
R19 P4	8595	0.34	0.52	11.8	100.0%	7.2	65.5%	0.093	0.067	1.07%	6.37
R19 P5	8226	0.34	0.34	--	--	10.8	98.2%	--	0.047	9.60%	6.37
R19 P6	3348	0.26	0.17	--	--	6.7	60.9%	--	0.033	-0.38%	6.37
R19A P1	2208	0.00	0.00	--	--	3.0	27.8%	--	0.033	0.00%	6.44
R19A P2	4217	0.00	0.00	--	--	2.2	20.4%	--	-0.003	1.28%	6.44
R19A P3	5032	0.00	0.00	--	--	2.2	20.4%	--	0.007	0.92%	6.44
R19A P4	1177	0.00	0.00	--	--	4.0	37.0%	--	-0.040	-0.47%	6.44
R20 P1	540	0.13	0.00	12.1	100.0%	9.9	94.3%	-0.017	-0.207	1.16%	6.7
R20 P2	627	0.17	0.34	12.1	100.0%	10.3	98.1%	-0.067	-0.250	0.39%	6.7

Table 4 (Continued)

Riffle Standpipe	Permeability Aug 99 (cm/hr)	Redds Per Square-Yd (20-ft radius)	Redds Per Square-Yd (10-ft radius)	D.O. Fall 98 (ppm)	D.O. Fall 98 Percent Saturation	D.O. Aug 99 (ppm)	D.O. Aug 99 Percent Saturation	VHG Fall 98	VHG 08/99	Gradient	Miles below Goodwin Dam
R20 P3	1235	0.09	0.00	--	--	9.8	93.3%	--	-0.260	1.10%	6.7
R20 P4	1848	0.39	0.17	--	--	10.1	96.19%	--	0.050	1.95%	6.7
R20 P5	7549	0.26	0.52	11.7	96.7%	9.7	92.4%	0.233	-0.133	3.38%	6.7
R20 P6	1592	0.26	0.17	12.1	100.0%	9.5	90.5%	0.233	0.027	3.12%	6.7
R27 P1	1566	0.05	0.17	--	--	4.2	39.6%	--	0.027	1.34%	7.7
R27 P2	1405	0.09	0.17	--	--	10.5	99.1%	--	0.033	8.77%	7.7
R27 P3	6927	0.30	0.52	11.5	99.1%	10.0	94.3%	0.100	-0.080	2.71%	7.7
R27 P4	4618	0.13	0.17	10.4	89.7%	9.6	90.6%	0.083	0.007	9.32%	7.7
R27 P5	4448	0.17	0.34	10.5	90.5%	9.2	86.8%	0.217	-0.127	0.00%	7.7
R27 P6	779	0.04	0.00	4.0	34.5%	4.4	41.5%	0.227	-0.030	1.69%	7.7
R28A P1	80	0.13	0.00	10.5	86.1%	3.6	35.3%	0.050	0.050	-1.67%	8.3
R28A P2	1258	0.26	0.52	7.4	60.7%	3.8	37.3%	0.067	0.017	4.12%	8.3
R28A P3	167	0.26	0.17	8.8	77.9%	2.4	23.5%	0.100	0.033	2.61%	8.3
R28A P4	1452	0.43	0.34	10.9	96.5%	3.3	32.4%	0.040	0.033	0.52%	8.3
R29 P1	80	0.43	0.69	8.0	63.5%	8.2	68.3%	0.167	0.033	3.90%	8.75
R29 P2	1505	0.30	0.34	3.0	26.1%	10.5	87.5%	0.167	-0.160	6.90%	8.75
R29 P3	80	0.00	0.00	4.4	34.9%	6.8	56.7%	0.200	0.117	-8.43%	8.75
R29 P4	80	0.00	0.00	3.5	27.8%	1.8	15.0%	0.167	-0.050	2.50%	8.75
R29 P5	251	0.21	0.34	--	--	3.9	32.5%	--	-0.033	3.73%	8.75
R29 P6	251	0.26	0.34	--	--	3.0	25.0%	--	-0.070	0.71%	8.75
R43 P1	865	0.17	0.52	--	--	8.2	75.2%	--	-0.093	6.36%	11.6
R43 P2	532	0.17	0.17	--	--	7.9	72.5%	--	0.000	4.67%	11.6
R43 P3	285	0.09	0.17	--	--	7.2	66.1%	--	0.107	4.38%	11.6
R43 P4	251	0.04	0.00	5.3	43.8%	4.5	41.3%	0.167	0.180	2.22%	11.6
R43 P5	372	0.17	0.34	--	--	6.0	55.0%	--	0.067	1.30%	11.6

Table 4 (Continued)

Riffle Standpipe	Permeability Aug 99 (cm/hr)	Redds Per Square-Yd (20-ft radius)	Redds Per Square-Yd (10-ft radius)	D.O. Fall 98 (ppm)	D.O. Fall 98 Percent Saturation	D.O. Aug 99 (ppm)	D.O. Aug 99 Percent Saturation	VHG Fall 98	VHG 08/99	Gradient	Miles below Goodwin Dam
R43 P7	80	0.30	0.34	8.9	73.6%	3.1	28.4%	0.067	0.000	0.48%	11.6
R43 P8	80	0.26	0.17	11.6	95.9%	--	--	0.200	0.000	0.00%	11.6
R58 P1	858	0.00	0.00	8.6	74.1%	7.8	78.0%	0.100	0.037	4.44%	14
R58 P2	204	0.00	0.00	8.4	72.4%	7.2	72.0%	0.117	0.047	5.69%	14
R58 P3	801	0.00	0.00	6.4	55.2%	6.9	69.0%	0.167	0.070	0.75%	14
R58 P4	270	0.00	0.00	8.6	74.1%	7.6	76.0%	0.100	0.013	0.50%	14
R58 P5	327	0.00	0.00	--	--	7.0	70.0%	--	0.010	-0.83%	14
R58 P6	447	0.00	0.00	--	--	7.6	76.0%	--	0.013	0.16%	14
R59 P1	290	0.00	0.00	9.5	81.9%	7.2	70.6%	-0.050	--	0.00%	14.1
R59 P2	2860	0.00	0.00	10.3	88.8%	7.3	71.6%	0.183	0.017	0.00%	14.1
R59 P3	670	0.00	0.00	7.9	68.1%	7.6	74.5%	0.100	-0.013	-0.79%	14.1
R59 P4	1167	0.00	0.00	11.3	97.4%	7.2	70.6%	0.100	-0.047	-0.66%	14.1
R59 P5	1665	0.00	0.00	--	--	7.1	69.6%	--	-0.013	-0.88%	14.1
R59 P6	878	0.00	0.00	--	--	6.5	63.7%	--	0.087	-2.12%	14.1
R76 P1	995	0.00	0.00	7.5	68.8%	5.8	55.2%	0.017	-0.007	2.00%	18.15
R76 P2	1220	0.00	0.00	--	--	3.9	37.1%	--	-0.020	46.15%	18.15
R76 P3	1618	0.00	0.00	10.4	95.4%	6.5	61.9%	0.083	-0.040	-0.45%	18.15
R76 P4	1194	0.00	0.00	9.7	89.0%	7.8	74.3%	0.400	0.070	9.42%	18.15
R76 P5	1419	0.00	0.00	--	--	7.8	74.3%	--	0.000	0.68%	18.15
R76 P6	3201	0.00	0.00	--	--	7.3	69.5%	--	-0.027	-0.92%	18.15
R78 P1	1170	0.00	0.00	9.1	81.3%	6.2	66.7%	0.250	-0.013	8.12%	18.3
R78 P2	418	0.00	0.00	--	--	7.2	77.4%	--	0.013	3.16%	18.3
R78 P3	409	0.00	0.00	9.9	79.2%	6.7	72.0%	0.140	-0.023	-1.98%	18.3
R78 P4	1163	0.00	0.00			6.0	64.5%		0.060	-1.40%	18.3
R78 P5	255	0.00	0.00	10.1	80.8%	5.5	59.1%	0.283	-0.070	1.31%	18.3

Table 5. Median diameter (d_{50}) and percentage finer than 6.35 mm of the surface sample, and the percentage finer than 1 mm of the subsurface sample for 50 bulk samples collected in the Stanislaus River in August 1999.

	Surface Sample		Subsurface Sample
Site and Piezometer Number	D50	Percent finer than 6.35 mm	Percent finer than 1 mm
TMA P1	12	35.7%	16.2%
TMA P2	44	0.4%	4.1%
TMA P4	55	0.02%	0.6%
TM1 P3	38	8.6%	9.7%
TM1 P5	35	7.3%	5.0%
TM1 P6	55	6.1%	2.2%
R1 P3	63	10.8%	3.4%
R1 P4	72	4.7%	3.7%
R1 P5	78	2.5%	4.7%
R5 P1	45	16.5%	12.5%
R5 P2	35	21.8%	13.5%
R10 P3	38	15.7%	10.8%
R10 P4	31	19.0%	11.4%
R10 P5	16	28.1%	6.9%
R12 P3	24	17.1%	7.7%
R12 P5	35	13.6%	8.7%
R12A P2	29	9.6%	12.1%
R12B P1	35	5.6%	3.9%
R12B P3	33	18.5%	14.7%
R14 P4	19	21.0%	13.0%
R14A P2	20	28.4%	18.8%
R15 P2	28	26.1%	26.2%
R15 P3	27	18.6%	6.9%
R16 P3	35	10.8%	9.2%
R19 P3	25	13.8%	8.5%
R19 P4	50	4.0%	1.8%
R19 P6	82	9.7%	4.5%
R19A P4	105	1.2%	11.9%
R20 P2	46	3.7%	0.2%
R20 P6	35	5.3%	6.1%
R27 P2	39	7.9%	12.2%
R27 P4	30	3.9%	5.4%
R27 P6	46	0.4%	12.3%
R28A P1	34	10.1%	14.2%
R28A P2	45	6.2%	13.3%

Table 5 (Continued)

Site and Piezometer Number	Surface Sample D50	Surface Sample Percent finer than 6.35 mm	Subsurface Sample Percent finer than 1 mm
R29 P2	25	17.8%	4.9%
R29 P4	10	38.3%	35.8%
R29 P6	14	36.3%	17.4%
R43 P3	23	17.4%	--
R43 P5	40	15.1%	5.5%
R43 P7	25	17.9%	17.1%
R58 P3	14	7.8%	31.2%
R58 P5	12	35.1%	27.8%
R58 P6	20	21.6%	24.6%
R59 P6	9.5	42.4%	26.8%
R76 P1	42	3.2%	10.4%
R76 P3	35	12.9%	9.3%
R76 P5	35	13.4%	9.4%
R78 P3	33	14.7%	5.9%
R78 P5	24	24.0%	14.4%

Table 6. The weight of substrate retained in 63.0, 31.5, 16.0, 9.5, 8.0, 4.0, 2.0, 1.0, and 0.85 mm sieves for bulk samples collected from the surface and subsurface layers at 50 sites within the 25 Knights Ferry Gravel Replenishment riffles in the Stanislaus River in August 1999. The weights of the substrate retained in the 16.0 mm and 25.4 mm sieves presented below are estimates and the true weight for the 16 mm sieve is the combined weight for the 16.0 and 25.4 mm sieves in the table.

		Weight (grams) of Substrate Retained in Each Sieve Size											
Site	Layer	63.0 mm	31.5 mm	25.4 mm	16.0 mm	9.5 mm	8.0 mm	4.00 mm	2.0 mm	1.0 mm	0.85 mm	Pan	Total Wt
TMA P1	Surface	253	3,745	1,448	3,076	5,062	1,374	4,342	2,520	1,895	387	2,560	26,662
	Subsurface	0	3,021	1,411	2,998	4,319	1,197	3,986	2,661	2,166	518	3,679	25,956
TMA P2	Surface	6,090	15,146	4,205	2,804	455	22	11	3	5	3	92	28,836
	Subsurface	458	3,051	2,764	1,843	853	51	60	13	28	17	370	9,508
TMA P4	Surface	7,523	11,899	718	479	34	4	0	1	1	1	1	20,661
	Subsurface	10,500	9,536	3,229	2,152	949	160	326	92	52	14	139	27,149
TM1 P3	Surface	4,161	11,975	1,730	2,114	2,056	547	878	529	286	95	813	25,184
	Subsurface	1,507	6,928	1,881	2,299	2,560	695	1,923	966	864	256	1,853	21,732
TM1 P5	Surface	3,814	10,560	2,079	3,119	2,874	820	2,055	556	180	29	121	26,207
	Subsurface	1,196	5,647	1,804	2,707	3,705	1,246	3,391	1,478	964	213	963	23,314
TM1 P6	Surface	12,037	8,632	1,277	1,916	1,392	275	734	348	253	69	632	27,565
	Subsurface	5,664	8,518	1,696	2,543	2,100	562	1,228	420	280	64	445	23,520
R1 P3	Surface	15,608	5,149	1,148	2,438	1,794	546	1,894	1,216	631	94	453	30,971
	Subsurface	7,658	4,000	1,512	3,212	2,682	934	2,520	1,370	855	126	746	25,615
R1 P4	Surface	17,148	6,079	783	1,665	1,325	379	598	479	292	97	192	29,037
	Subsurface	10,984	5,948	1,282	2,725	1,325	1,092	3,895	2,795	1,611	376	856	32,889
R1 P5	Surface	20,824	7,085	800	1,701	663	132	154	302	177	164	76	32,078
	Subsurface	4,754	8,164	1,924	4,089	2,135	532	1,259	852	765	148	1,056	25,678
R5 P1	Surface	13,947	6,619	1,358	2,886	2,429	613	1,937	1,206	1,196	325	2,002	34,518
	Subsurface	3,103	4,973	1,487	3,159	3,418	1,057	3,396	2,242	2,236	663	2,934	28,668
R5 P2	Surface	7,587	6,459	780	1,658	2,413	623	1,799	1,108	1,151	274	2,248	26,100
	Subsurface	1,501	3,153	780	1,658	1,727	657	1,774	1,018	985	268	1,794	15,315
R10 P3	Surface	8,013	8,105	1,334	2,835	1,926	477	1,465	1,051	873	185	1,514	27,778
	Subsurface	5,271	3,682	1,370	2,912	2,763	800	2,728	1,784	1,330	443	2,285	25,368

Table 6 (Continued)

Site	Layer	63.0 mm	31.5 mm	25.4 mm	16.0 mm	9.5 mm	8.0 mm	4.00 mm	2.0 mm	1.0 mm	0.85 mm	Pan	Total Wt
		Weight (grams) of Substrate Retained in Each Sieve Size											
R10 P4	Surface	2,029	12,046	1,682	3,575	1,970	567	1,703	1,314	1,315	407	1,438	28,046
	Subsurface	2,714	6,741	1,372	2,915	2,260	635	2,461	1,951	2,186	407	2,586	26,228
R10 P5	Surface	434	6,634	2,268	4,820	4,031	1,114	3,260	2,200	1,743	265	2,334	29,103
	Subsurface	763	4,282	1,685	3,582	3,841	1,012	3,103	2,120	1,521	210	1,407	23,526
R12 P3	Surface	3,179	7,481	1,867	3,967	2,983	813	2,205	1,217	771	143	1,171	25,797
	Subsurface	2,573	4,344	1,797	3,820	3,233	1,070	3,224	2,087	1,436	248	1,717	25,549
R12 P5	Surface	4,367	12,980	1,693	3,599	2,262	452	1,364	851	464	76	2,017	30,125
	Subsurface	2,486	7,748	1,794	3,812	2,505	614	1,790	1,261	933	147	2,043	25,133
R12A	Surface	1,043	18,883	4,748	10,090	2,796	550	1,481	955	992	232	1,212	42,982
	Subsurface	965	7,155	2,226	4,730	2,960	731	2,375	1,729	3,240	711	2,889	29,711
R12B	Surface	4,746	11,514	2,154	4,577	3,181	622	1,314	402	199	38	324	29,071
	Subsurface	1,622	6,467	1,920	4,079	3,434	750	2,003	986	645	115	766	22,787
R12B	Surface	3,573	12,287	2,039	4,334	2,006	491	1,492	1,029	1,356	478	2,170	31,255
	Subsurface	2,233	8,347	1,941	4,126	3,014	659	2,485	2,268	5,022	737	4,445	35,277
R14 P4	Surface	795	9,318	2,803	5,955	4,370	1,485	2,866	1,461	1,020	340	2,689	33,101
	Subsurface	663	3,327	1,989	4,226	4,089	904	2,744	1,612	2,406	669	2,619	25,248
R14A	Surface	1,209	9,638	2,709	5,756	3,141	796	2,270	1,686	3,048	578	3,225	34,056
	Subsurface	3,124	3,975	1,254	2,666	2,141	603	2,124	1,735	2,164	748	3,839	24,373
R15 P2	Surface	4,442	10,283	1,529	3,250	2,121	697	1,687	970	1,057	982	4,321	31,339
	Subsurface	1,934	4,048	1,604	3,409	2,237	688	1,994	1,371	1,658	545	6,166	25,654
R15 P3	Surface	4,914	8,603	2,131	4,528	2,986	711	2,067	1,309	1,452	362	1,521	30,584
	Subsurface	448	7,055	1,780	3,783	3,432	871	2,417	1,555	1,702	358	1,337	24,738
R16 P3	Surface	5,491	11,129	2,501	5,315	2,196	468	1,304	870	815	170	867	31,126
	Subsurface	1,420	7,983	2,077	4,414	2,931	734	2,715	2,259	2,143	460	2,237	29,373

Table 6 (Continued)

Site	Layer	Weight (grams) of Substrate Retained in Each Sieve Size											
		63.0 mm	31.5 mm	25.4 mm	16.0 mm	9.5 mm	8.0 mm	4.00 mm	2.0 mm	1.0 mm	0.85 mm	Pan	Total Wt
R19 P3	Surface	893	10,419	2,772	5,891	3,995	1,075	2,719	1,362	559	60	877	30,622
	Subsurface	2,341	5,923	2,400	5,099	3,947	997	2,901	1,965	1,108	153	2,327	29,161
R19 P4	Surface	13,740	10,051	1,760	3,740	2,916	389	952	414	200	67	228	34,456
	Subsurface	2,203	4,050	1,373	2,918	2,260	614	1,685	933	494	60	237	16,827
R19 P6	Surface	21,113	1,832	711	1,510	1,384	371	1,146	876	759	114	627	30,443
	Subsurface	10,719	5,701	1,395	2,963	2,347	716	1,894	1,400	1,203	188	1,148	29,674
R19A	Surface	26,809	0	238	505	348	64	102	48	39	12	200	28,365
	Subsurface	10,052	5,388	1,395	2,964	2,770	500	1,846	1,180	2,585	613	3,261	32,554
R20 P2	Surface	10,864	11,479	1,602	3,403	1,702	403	782	345	242	31	126	30,979
	Subsurface	4,403	4,311	760	1,616	854	169	285	91	41	4	25	12,559
R20 P6	Surface	8,865	8,290	1,831	3,890	2,501	565	1,935	1,437	1,328	205	741	31,588
	Subsurface	2,053	3,946	1,359	2,889	2,360	649	2,173	1,738	1,620	253	977	20,017
R27 P2	Surface	5,482	12,631	2,073	4,405	1,230	201	496	300	408	109	1,192	28,527
	Subsurface	0	6,606	1,945	4,134	2,202	367	1,214	828	1,142	287	2,273	20,998
R27 P4	Surface	1,010	13,820	3,647	7,751	1,818	105	157	99	187	60	710	29,364
	Subsurface	653	7,065	3,387	7,197	2,419	210	444	235	408	113	1,132	23,263
R27 P6	Surface	7,588	15,894	1,724	3,664	419	20	27	11	15	5	73	29,440
	Subsurface	3,044	4,127	1,582	3,361	685	48	101	94	157	711	1,148	15,058
R28A	Surface	2,285	11,841	2,124	4,514	1,778	421	766	348	447	164	1,291	25,979
	Subsurface	0	5,251	1,247	2,649	1,474	375	664	435	587	187	1,911	14,780
R28A	Surface	8,299	10,310	1,283	2,727	1,305	262	506	278	312	93	665	26,040
	Subsurface	5,188	6,826	1,800	3,824	3,078	809	2,028	1,595	2,132	784	3,412	31,476
R29 P2	Surface	4,761	8,271	1,856	3,944	3,391	942	1,986	1,786	857	286	1,313	29,392
	Subsurface	2,820	7,286	1,786	3,795	3,533	1,020	2,513	1,298	946	185	1,097	26,279

Table 6 (Continued)

Site	Layer	Weight (grams) of Substrate Retained in Each Sieve Size											
		63.0 mm	31.5 mm	25.4 mm	16.0 mm	9.5 mm	8.0 mm	4.00 mm	2.0 mm	1.0 mm	0.85 mm	Pan	Total Wt
R29 P4	Surface	0	6,604	1,572	3,342	3,383	1,159	2,905	1,632	1,403	428	5,974	28,402
	Subsurface	0	2,505	1,368	2,906	4,522	1,353	3,400	1,635	1,689	522	10,301	30,201
R29 P6	Surface	1,067	5,078	1,691	3,594	2,889	901	2,881	1,892	1,924	342	3,906	26,165
	Subsurface	3,160	4,015	1,632	3,467	3,416	1,288	3,113	2,376	2,300	398	4,805	29,970
R43 P3	Surface	3,428	10,376	3,052	6,487	4,512	1,133	3,081	1,792	1,770	328	980	36,939
R43 P5	Surface	9,900	4,521	1,239	2,634	2,437	569	1,596	1,027	1,106	369	645	26,043
	Subsurface	3,916	2,437	897	1,906	1,723	427	1,170	716	849	204	615	14,860
R43 P7	Surface	2,964	8,298	2,337	4,965	2,714	647	1,712	980	1,451	412	1,284	27,764
	Subsurface	2,731	1,710	1,130	2,400	1,675	553	1,314	1,055	1,944	356	2,635	17,503
R58 P3	Surface	0	3,801	2,713	5,764	4,429	1,016	3,083	1,473	1,496	520	5,103	29,398
	Subsurface	0	3,029	1,850	3,931	3,643	919	3,223	1,776	1,708	891	8,196	29,166
R58 P5	Surface	0	2,664	2,832	6,019	4,561	1,095	3,202	1,540	1,365	444	5,200	28,922
	Subsurface	0	2,028	1,847	3,926	5,121	911	2,634	1,346	1,603	2,024	5,457	26,897
R58 P6	Surface	491	7,217	2,387	5,071	3,170	653	1,966	1,211	790	174	2,358	25,488
	Subsurface	0	4,258	2,227	4,731	3,052	809	2,899	1,912	1,349	368	6,578	28,183
R59 P6	Surface	2,064	3,932	1,464	3,111	3,155	870	2,824	1,548	1,500	445	6,861	27,774
	Subsurface	0	3,461	1,044	2,220	2,016	629	2,073	1,240	1,294	339	4,789	19,105
R76 P1	Surface	4,100	15,310	1,595	3,390	951	160	365	154	127	42	351	26,545
	Subsurface	1,656	6,519	2,506	1,180	1,157	274	992	637	532	258	1,541	17,252
R76 P3	Surface	3,906	11,307	1,695	3,602	2,054	522	1,220	644	1,036	249	962	27,197
	Subsurface	2,999	6,677	2,001	4,251	2,635	664	1,656	1,153	1,552	348	2,059	25,995
R76 P5	Surface	4,553	12,858	1,463	3,108	2,794	784	2,013	957	1,089	271	773	30,663
	Subsurface	1,826	7,070	1,658	3,522	3,031	772	2,444	1,602	2,416	685	1,836	26,862
R78 P3	Surface	4,493	9,644	1,736	3,689	2,288	565	1,690	1,035	801	138	1,202	27,281
	Subsurface	1,600	5,672	2,110	4,485	2,693	683	2,073	1,461	1,196	185	1,194	23,352
R78 P5	Surface	3,475	7,754	1,364	2,898	2,825	717	2,449	1,639	1,306	306	1,925	26,658
	Subsurface	1,031	4,920	1,092	2,320	2,756	815	2,819	1,944	1,701	569	2,687	22,654

Table 7. Regression of redd density at riffles in the Stanislaus River versus habitat variables measured in fall 1998 and August 1999.

Redd Density = -0.0099 * Distance Below Goodwin Dam (miles) + 0.167 *adj*-R^2 = 0.467, F = 19.41, P = 0.003, df = 21			
Variable in Model		**Student's *t***	***P***
Miles Below Goodwin Dam		-4.41	0.0003
Non Significant Variables	**Partial Correlations Controlled for Model Variable**	**Student's *t***	***P***
D.O. fall 1998	0.3039	1.39	0.180
D.O. August 1999	0.0933	0.41	0.688
Surface D.O.	-0.0309	-0.13	0.894
Streambed Gradient	0.3202	1.47	0.157
Ln Permeability	-0.0184	-0.08	0.937
VHG fall 1998	0.3015	1.38	0.184
VHG August 1999	0.1309	0.58	0.572
Fines < 1 mm in Subsurface	-0.3262	-1.50	0.149
Fines < 6.35 mm in Surface	-0.2254	-1.01	0.326
Surface Median Diameter	0.3784	1.78	0.091

Table 8. Regression of redd density in a 10-foot radius around standpipes versus habitat variables measured in fall 1998 and August 1999.

Redd Density in a 10-ft Radius = -0.02886 * Distance Below Goodwin Dam (miles) + 0.510 *adj*-R^2 = 0.210, F = 3.87, P = 0.005, df = 31			
Variable in Model		**Student's *t***	***P***
Miles Below Goodwin Dam		-3.04	0.00 5
Non Significant Variables	**Partial Correlations Controlled for Model Variable**	**Student's *t***	***P***
D.O. fall 1998	0.1108	0.60	0.553
D.O. August 1999	0.0044	0.19	0.854
Streambed Gradient	-0.0802	-0.43	0.668
Ln Permeability	0.1204	0.65	0.519
VHG fall 1998	-0.2005	-1.10	0.279
VHG August 1999	0.1924	1.06	0.300
Fines < 1 mm in Subsurface	-0.1285	-0.70	0.491
Fines < 6.35 mm in Surface	0.0457	0.25	0.807
Surface Median Diameter	0.2848	1.60	0.120

Table 9. Two regressions of redd density in a 20-foot radius around standpipes versus habitat variables, one with fall 1998 measurements and the other with August 1999 measurements.

Redd Density in a 20-ft Radius = -0.01807 * Distance Below Goodwin Dam (miles) + 0.17125* Dissolved Oxygen Fall 1998 + 0.192 *adj*-R^2 = 0.342, F = 18.93, $P \leq 0.00$, df = 72			
Variables in Model		**Student's *t***	***P***
Miles Below Goodwin Dam		-5.49	0.000
D.O. Measured Fall 1998		2.24	0.028
Non Significant Variables	**Partial Correlations Controlled for Model Variables**	**Student's *t***	***P***
Streambed Gradient	-0.0215	-0.18	0.859
Ln Permeability	0.0280	0.23	0.817
VHG fall 1998	-0.0580	-0.48	0.631

Redd Density in a 20-ft Radius = -0.0144 Distance Below Goodwin Dam (miles) - 0.4623 * Percent of Particles Finer than 1 mm in Subsurface Samples + 0.344 *adj*-R^2 = 0.285, F = 10.55, P = 0.002, df = 48			
Variables in Model		**Student's *t***	***P***
Miles Below Goodwin Dam		-3.30	0.002
Percent Finer than 1 mm		-1.80	0.078
Non Significant Variables	**Partial Correlations Controlled for Model Variables**	**Student's *t***	***P***
Streambed Gradient	-0.2074	-1.42	0.162
Ln Permeability	0.1016	0.69	0.497
D.O. Measured Fall 1999	-0.1177	-0.80	0.431
Fines < 6.35 mm in Surface	0.0729	0.49	0.626
Surface Median Diameter	0.0264	0.18	0.860

Table 10. Two regression of intragravel dissolved oxygen (D.O.) concentrations versus the percentage of substrate particles finer than 1 mm in the subsurface samples measured at at 25 riffles in the Stanislaus River: one with measurements made in Fall 1998 and the other with measurements made in August 1999.

D.O. Fall 1998 = -1.1615 * Percent Finer than 1 mm + 0.916 *adj-R*^{2} = 0.206, *F* = 5.60, *P* = 0.005, *df* = 31			
Variable in Model		**Student's *t***	***P***
Percent Finer than 1 mm		-3.01	0.005
Non Significant Variables	**Partial Correlations Controlled for Model Variables**	**Student's *t***	***P***
Miles Below Goodwin Dam	-0.1239	-0.67	0.507
Streambed Gradient	-0.0244	-0.13	0.896
Ln Permeability	-0.0435	-0.23	0.816
VHG Fall 1998	-0.1452	-0.79	0.436
Fines < 6.35 mm in Surface	0.0007	0.00	0.997
Surface Median Diameter	0.1483	0.81	0.426

D.O. August 1999 = -1.0818 * Percent Finer than 1 mm + 0.731 *adj-R*^{2} = 0.114, *F* = 7.17, *P* = 0.010, *df* = 48			
Variable in Model		**Student's *t***	***P***
Percent Finer than 1 mm		-2.68	0.0102
Non Significant Variables	**Partial Correlations Controlled for Model Variables**	**Student's *t***	***P***
Miles Below Goodwin Dam	0.1231	0.84	0.405
Streambed Gradient	0.2617	1.84	0.072
Ln Permeability	0.1252	0.86	0.397
VHG August 1999	-0.1327	-0.91	0.368
Fines < 6.35 mm in Surface	-0.1652	-1.14	0.262
Surface Median Diameter	-0.0003	-0.00	0.998

Table 11. Regression of the natural log of substrate permeability versus the percentage of substrate particles finer than 1 mm in the subsurface samples measured at standpipes in August 1999 at 25 riffles in the Stanislaus River.

Ln Permeability = -7.5186 * Percent Finer than 1 mm + 7.824 *adj*-R^2 = 0.233, F = 15.6, P = 0.0003, df = 48			
Variable in Model		**Student's *t***	***P***
Percent Finer than 1 mm		-3.94	0.0003
Non Significant Variables	**Partial Correlations Controlled for Model Variables**	**Student's *t***	***P***
Miles Below Goodwin Dam	-0.1407	-0.96	0.340
Streambed Gradient	-0.0206	-0.14	0.890
D.O. August 1999	0.1252	0.86	0.397
Fines < 6.35 mm in Surface	-0.0007	-0.00	0.397
Surface Median Diameter	-0.0430	-0.29	0.772

Table 12. Two regression of the percentage of substrate particles finer than 1 mm in the subsurface samples versus distance downstream from Goodwin Dam, intragravel dissolved oxygen (D.O.) concentration, and the natural log of permeability measured at standpipes, one in Fall 1998 and the other in August 1999 at 25 riffles in the Stanislaus River.

Percent Finer than 1 mm = 0.0042 * Miles Below Goodwin Dam - 0.0869 * D.O. August 1999 - 0.0234 * Ln Permeability + 0.2969 *adj-*R^2 = 0.317, *F* = 8.41, *P* = 0.0002, *df* = 48			
Variables in Model		**Student's *t***	***P***
Miles Below Goodwin Dam		1.99	0.0525
D.O. August 1999		-2.07	0.044
Ln Permeability		-2.71	0.010
Non Significant Variables	**Partial Correlations Controlled for Model Variables**	**Student's *t***	***P***
Streambed Gradient	0.0956	0.64	0.528

Percent Finer than 1 mm = - 0.1541 * D.O. Fall 1998 - 0.0279 * Ln Permeability + 0.4180 *adj-*R^2 = 0.392, *F* = 11.31, *P* = 0.0002, *df* = 32			
Variables in Model		**Student's *t***	***P***
D.O. Fall 1998		-2.63	0.013
Ln Permeability		-3.23	0.003
Non Significant Variables	**Partial Correlations Controlled for Model Variables**	**Student's *t***	***P***
Miles Below Goodwin Dam	0.1575	0.86	0.398
Streambed Gradient	-0.0793	-0.43	0.672

Table 13. Two regression of Vertical Hydraulic Gradient (VHG) versus intragravel dissolved oxygen (D.O.) concentration August 1999, one in Fall 1998 and the other in August 1999 at 25 riffles in the Stanislaus River.

VHG Fall 1998 was not correlated with any of the habitat variables			
Non Significant Variables	**Pearson Correlations**	**Student's *t***	***P***
Miles Below Goodwin Dam	0.0466	0.26	0.780
Streambed Gradient	0.0270	0.15	0.884
D.O. Fall 1998	-0.1227	-0.68	0.503
Ln Permeability	0.0882	0.48	0.631
Percent Finer than 1 mm	-0.0084	-0.05	0.959
Fines < 6.35 mm in Surface	-0.1027	-0.57	0.576
Surface Median Diameter	0.0060	0.03	0.974

VHG August 1999 was not correlated with any of the habitat variables			
Non Significant Variables	**Pearson Correlations**	**Student's *t***	***P***
Miles Below Goodwin Dam	0.1709	1.19	0.646
Streambed Gradient	-0.2605	-1.85	0.071
D.O. August 1999	-0.2072	-1.45	0.153
Ln Permeability	0.1502	1.04	0.303
Percent Finer than 1 mm	0.2398	1.69	0.097
Fines < 6.35 mm in Surface	0.0548	0.38	0.708
Surface Median Diameter	-0.0673	-0.46	0.646

APPENDIX 3

Contour Maps of Study Sites
Chinook Salmon Redd Locations Were Measured in Fall 1998 and Streambed Elevations Were Measured in August 1999

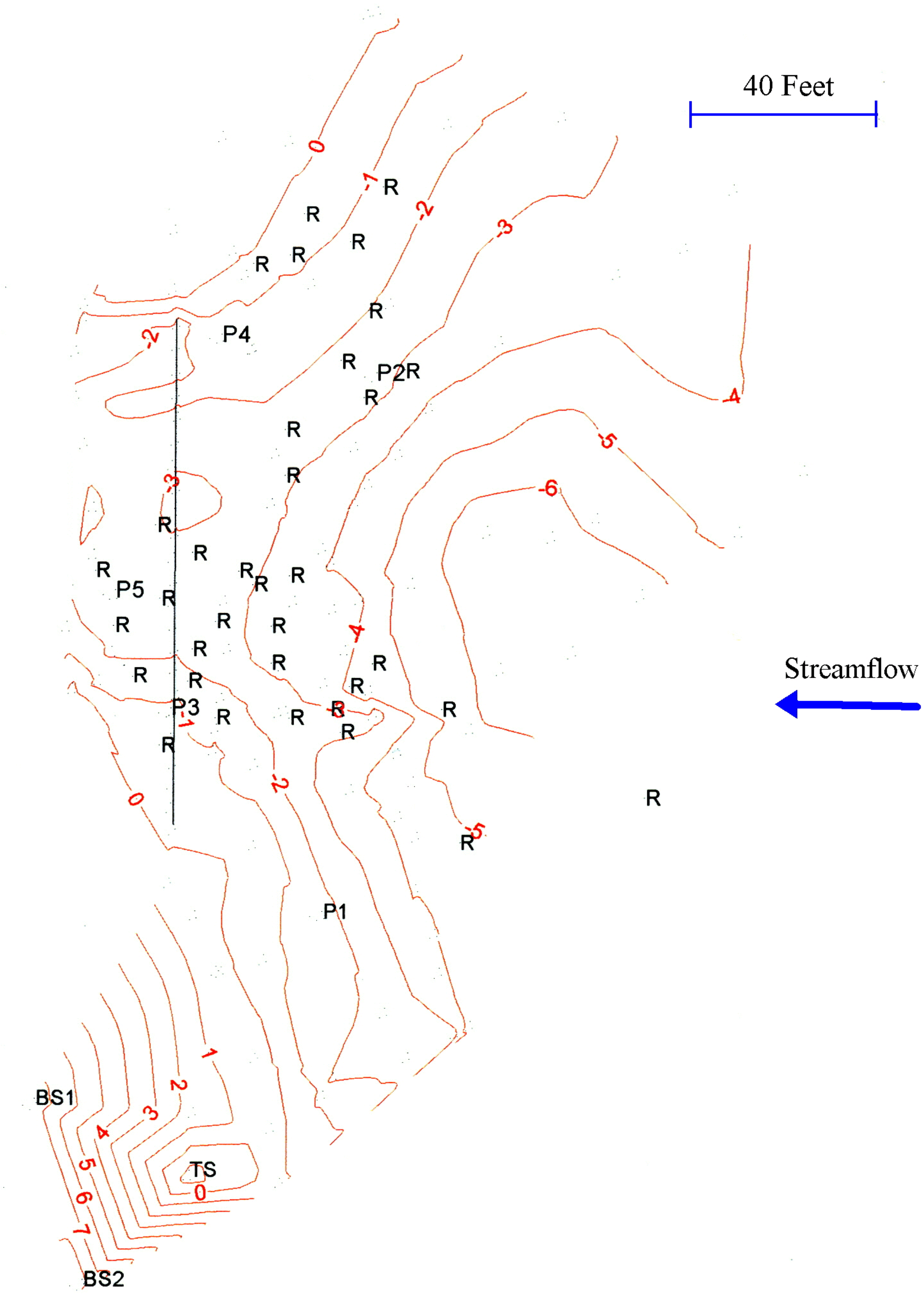


Figure 1. Contour map of Riffle TMA at rivermile 56.8 on the Stanislaus River on 4 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P5). The water surface elevation was 0.03 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 7.56 feet and at backsight 2 (BS2) is 8.06 feet.

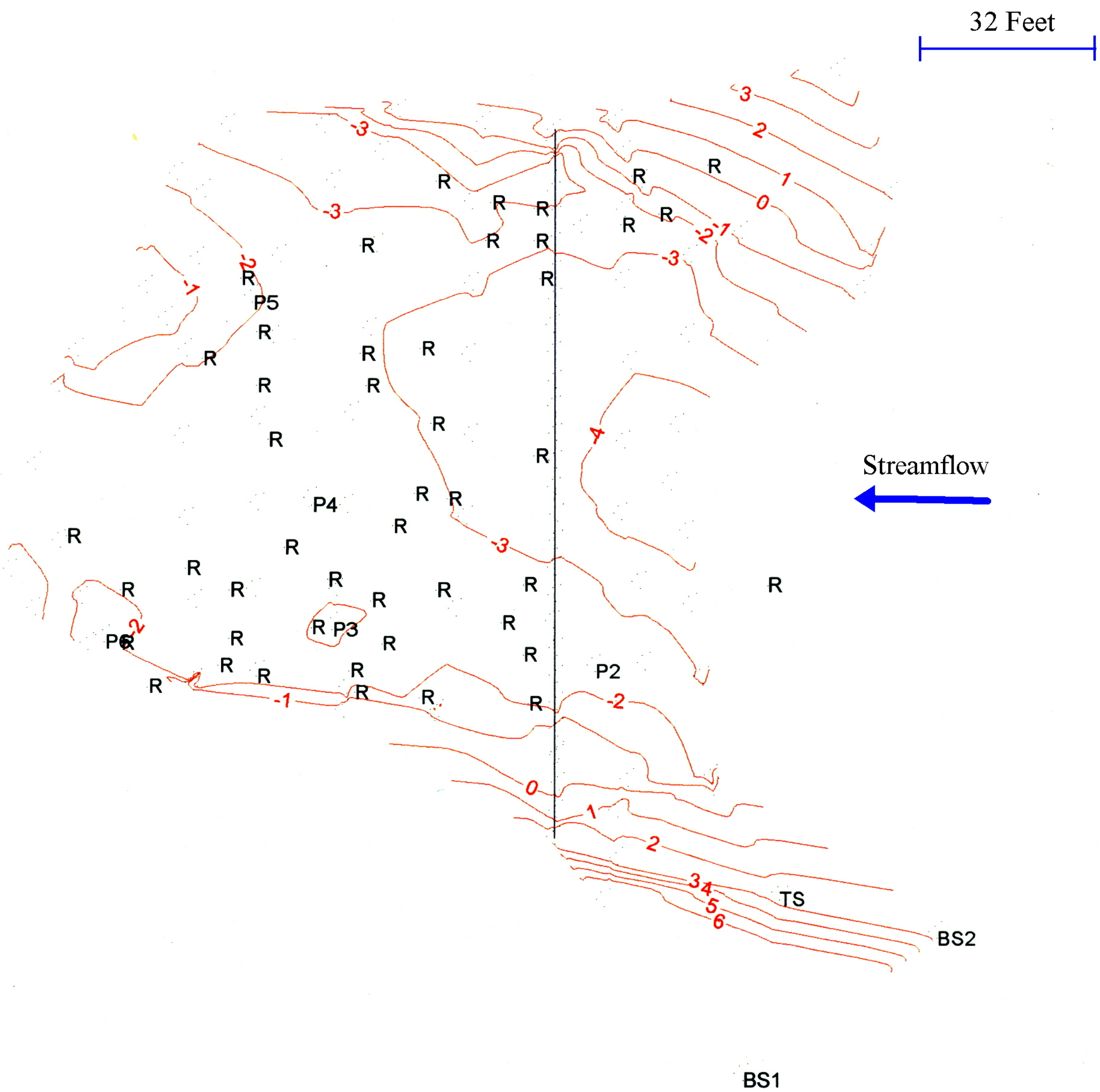


Figure 2. Contour map of Riffle TM1 at rivermile 56.6 on the Stanislaus River on 24 August 1999. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -0.595 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 16.51 feet and at backsight 2 (BS2) is 2.755 feet.

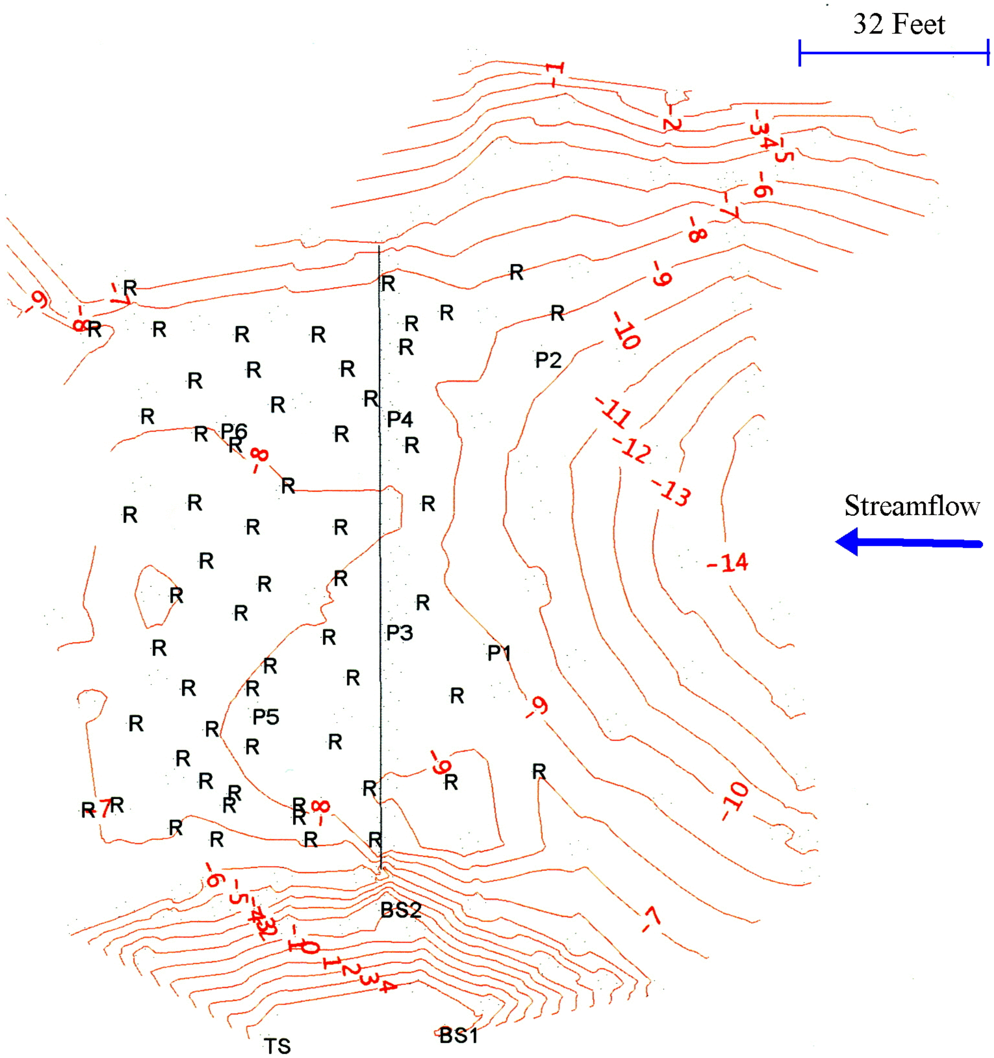


Figure 3. Contour map of Riffle R1 at rivermile 54.55 on the Stanislaus River on 3 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P5). The water surface elevation was -5.01 feet at the transect. The elevation of the marked rock at backsight 1 (BS1) is 5.825 feet and the nail at backsight 2 (BS2) was -0.245 feet. BS2 was since vandalized and replaced.

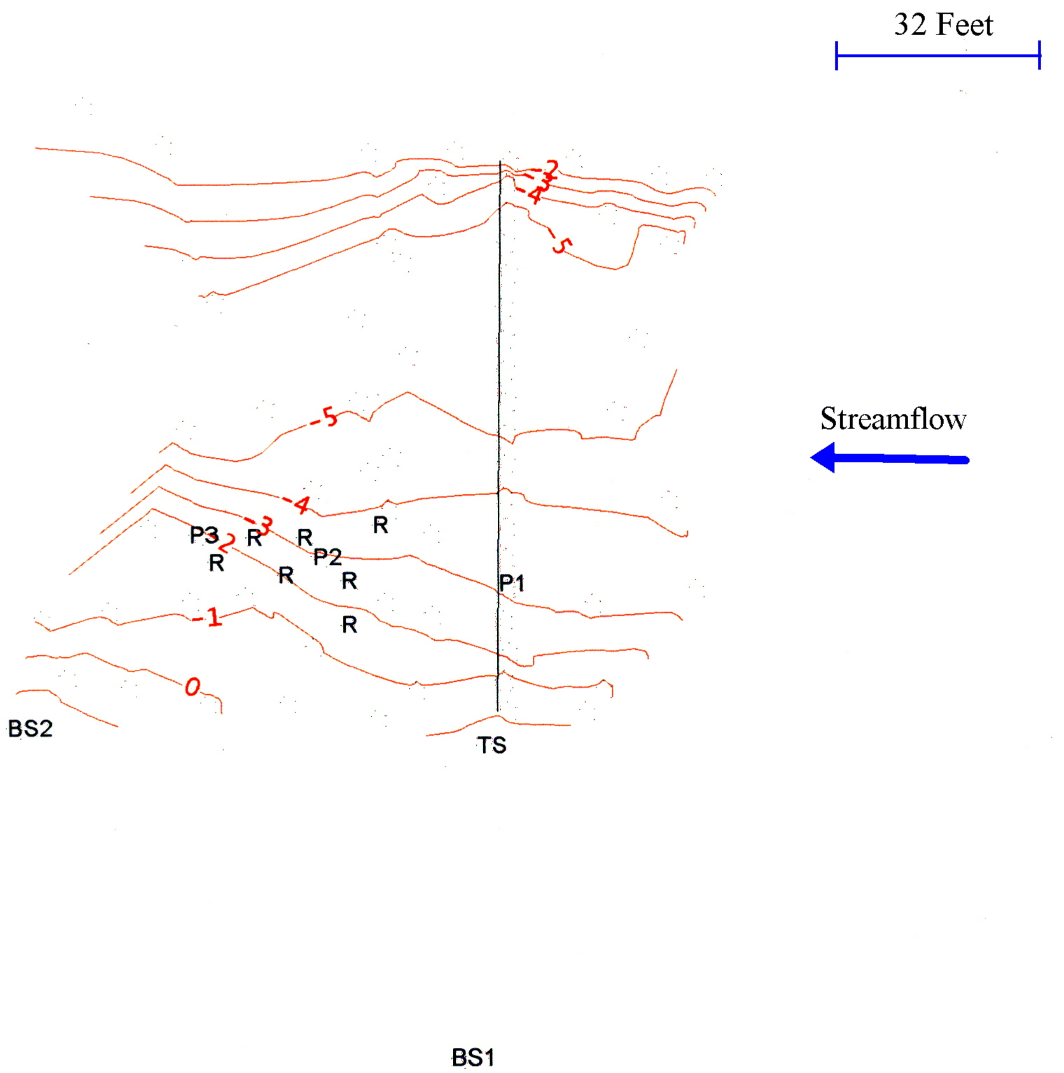


Figure 4. Contour map of Riffle R5 at rivermile 53.9 on the Stanislaus River on 5 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P3). The water surface elevation was -0.88 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.705 feet and at backsight 2 (BS2) is 2.145 feet.

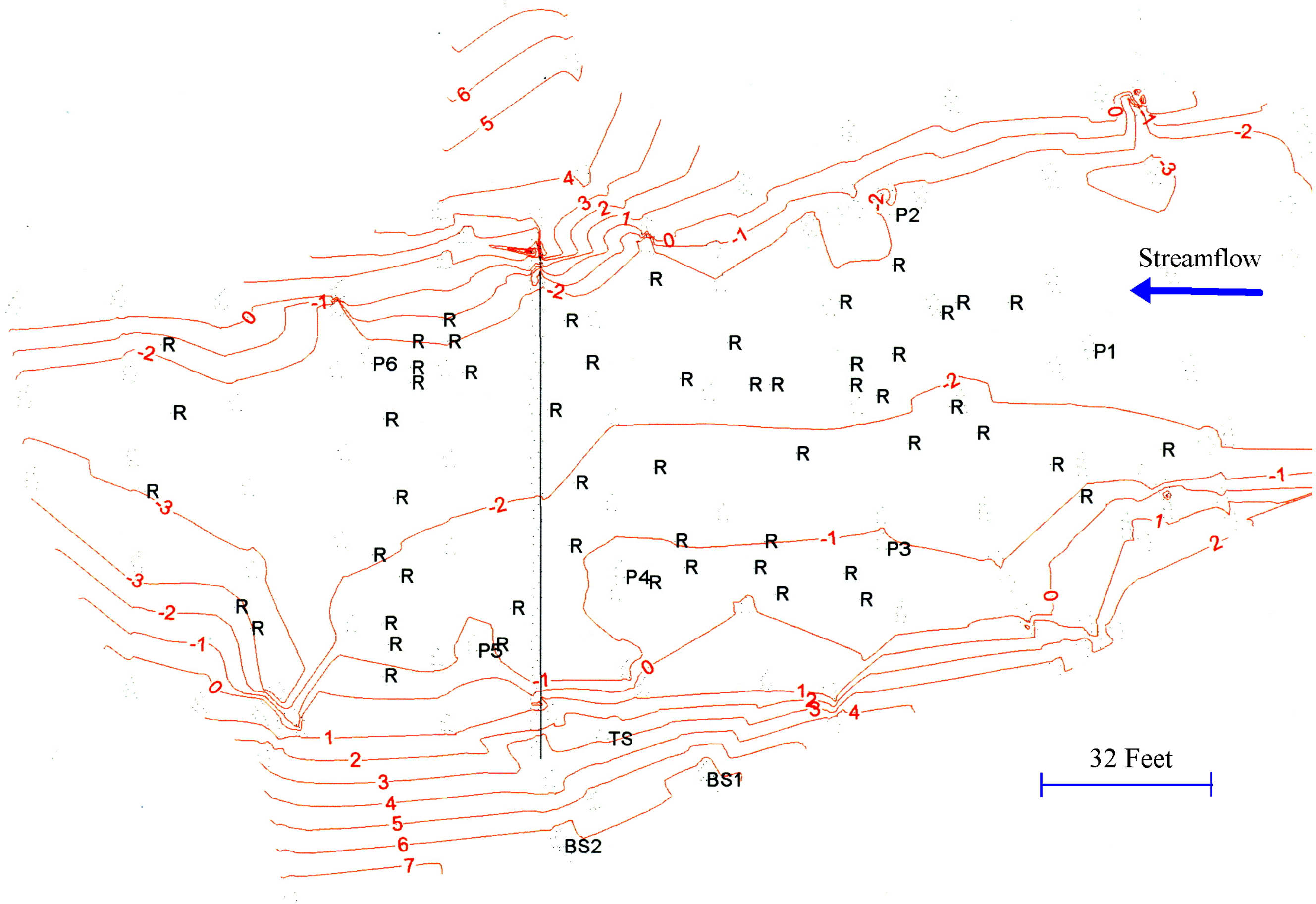


Figure 5. Contour map of Riffle R10 at rivermile 53.5 on the Stanislaus River on 23 August 1999. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was 0.86 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is 6.355 feet and at backsight 2 (BS2) is 6.44 feet.

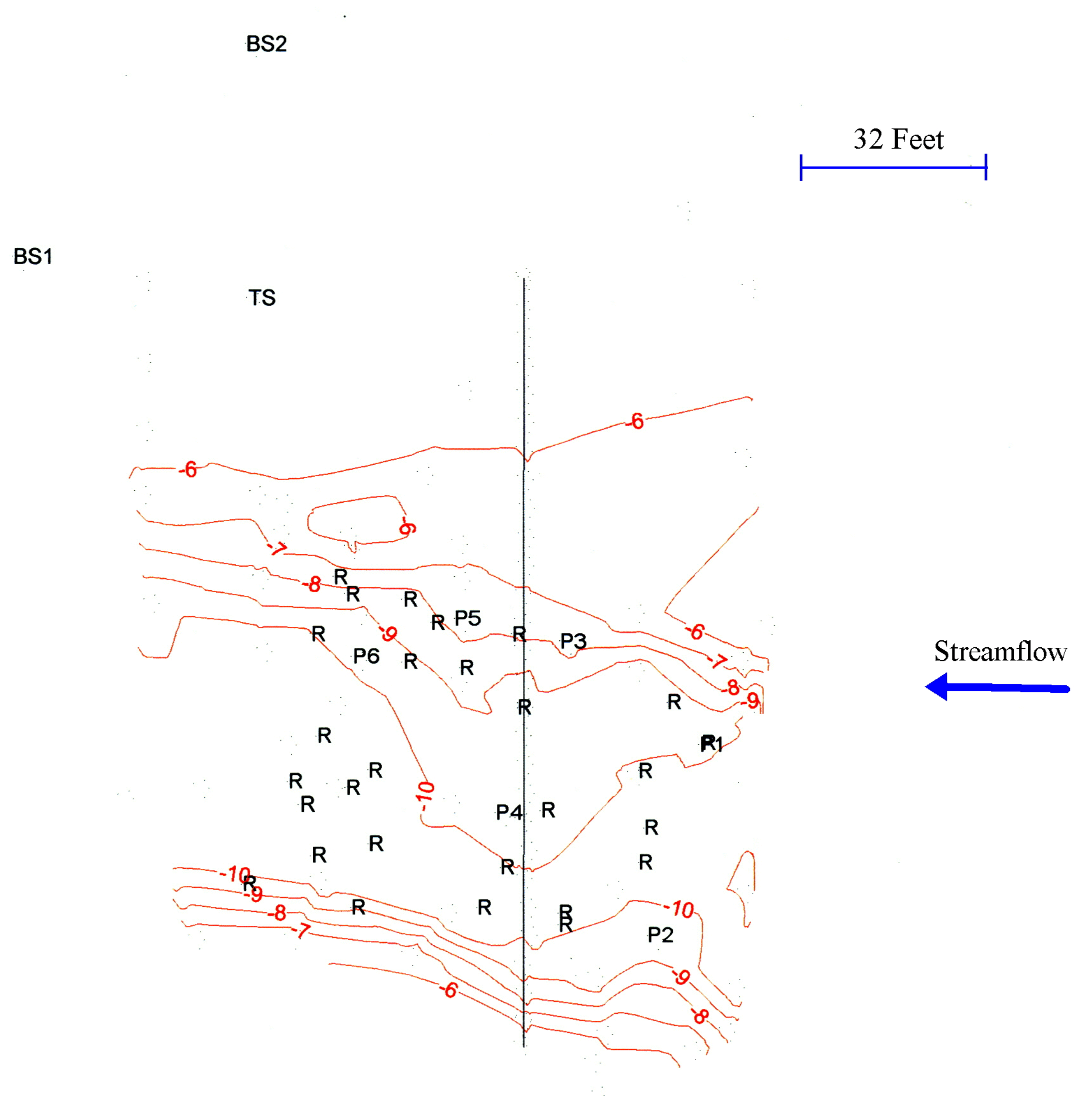


Figure 6. Contour map of Riffle R12 at rivermile 53.3 on the Stanislaus River on 23 August 1999. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -6.48 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.785 feet and at backsight 2 (BS2) is 5.20 feet.

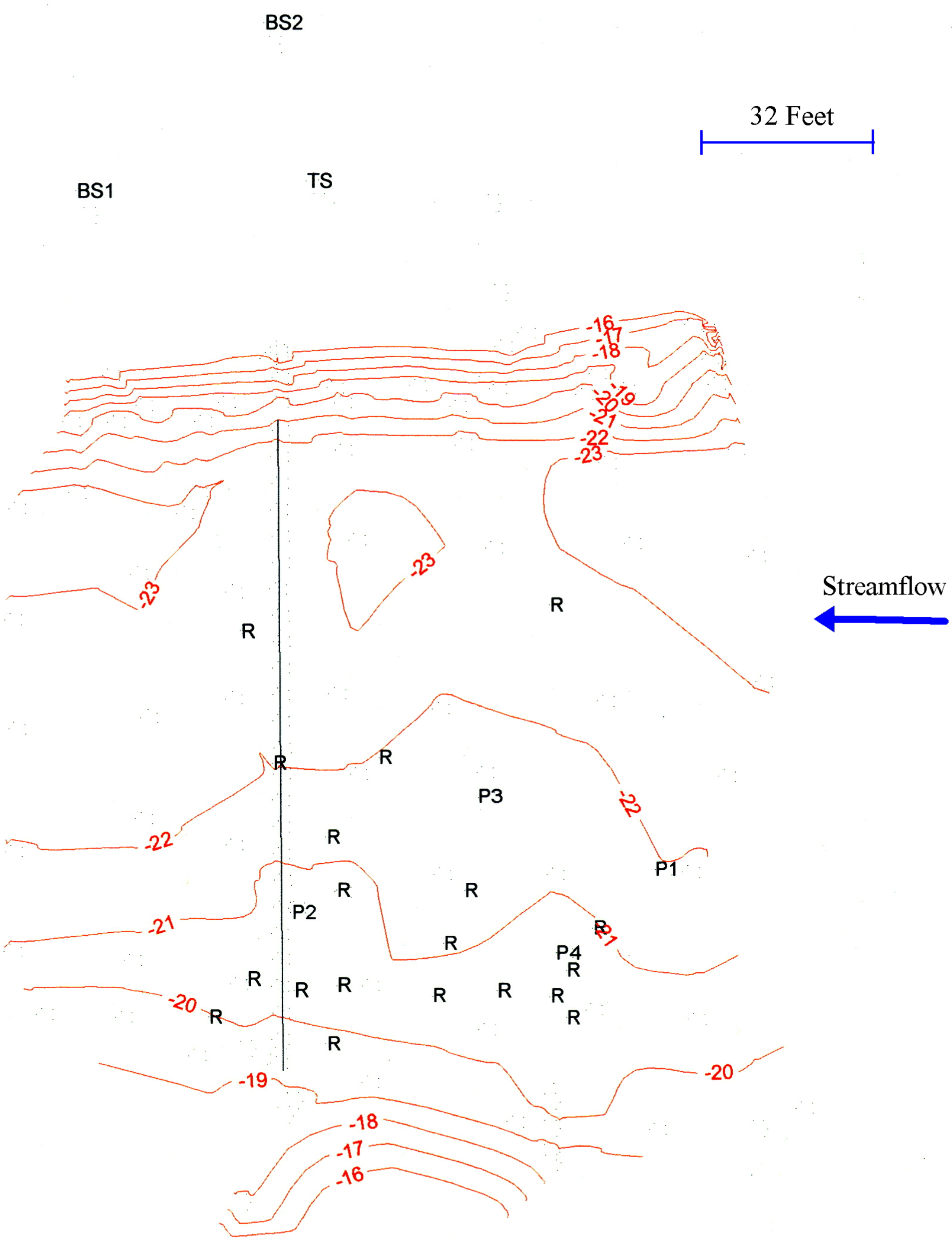


Figure 7. Contour map of Riffle R12A at rivermile 52.82 on the Stanislaus River on 1 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P4). The water surface elevation was -19.38 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is -0.355 feet and at backsight 2 (BS2) is 0.975 feet.

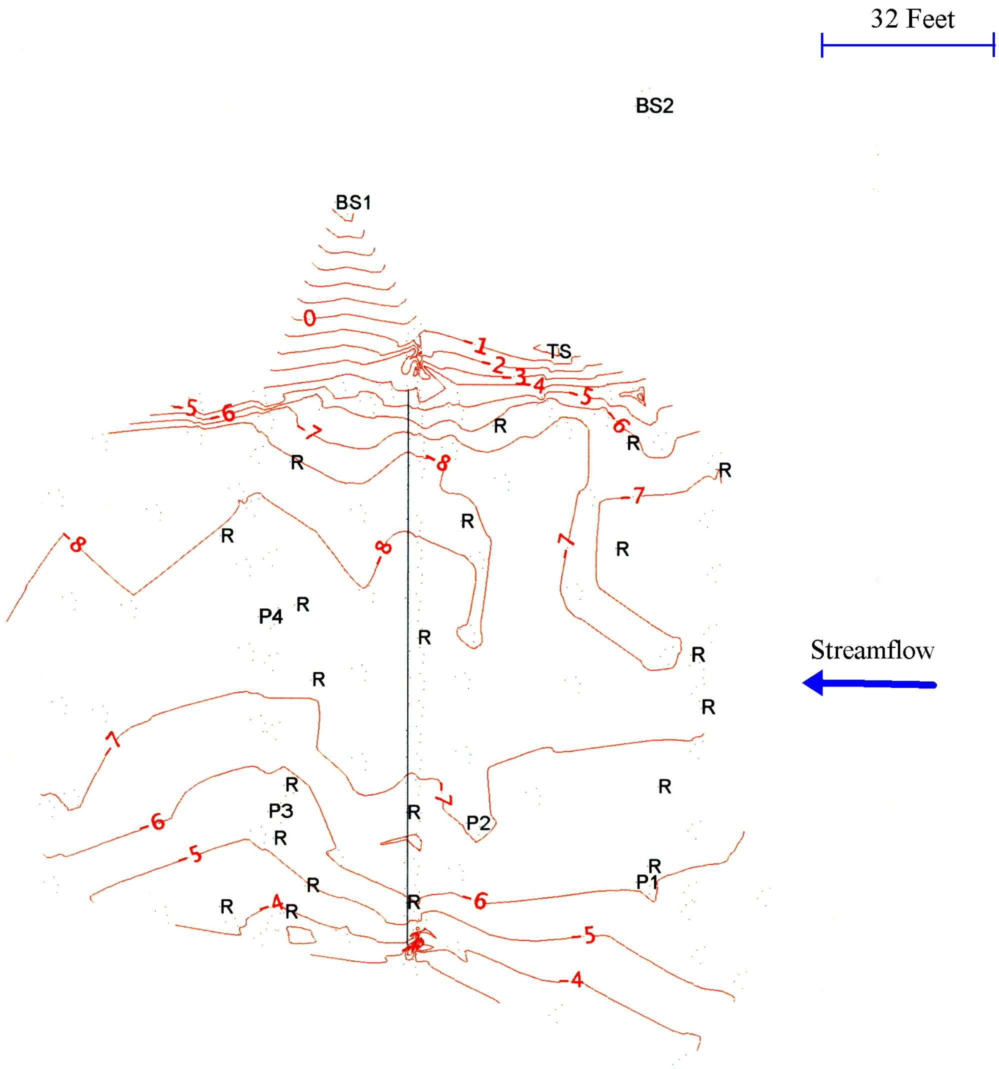


Figure 8. Contour map of Riffle R12B at rivermile 52.77 on the Stanislaus River on 11 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P4). The water surface elevation was -4.215 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is 6.375 feet and at backsight 2 (BS2) was 15.14 feet. BS2 was disturbed and has since been replaced.

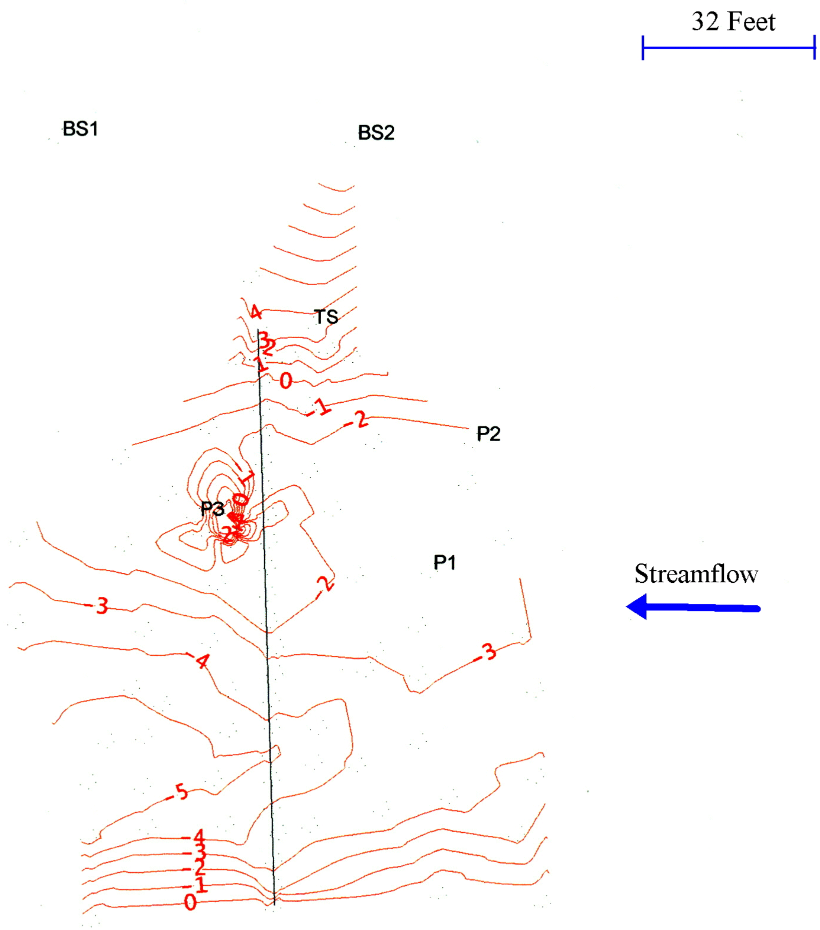


Figure 9. Contour map of Riffle R13 at rivermile 52.73 on the Stanislaus River on 12 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P3). The water surface elevation was 0.765 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is 9.715 feet and at backsight 2 (BS2) is 10.89 feet.

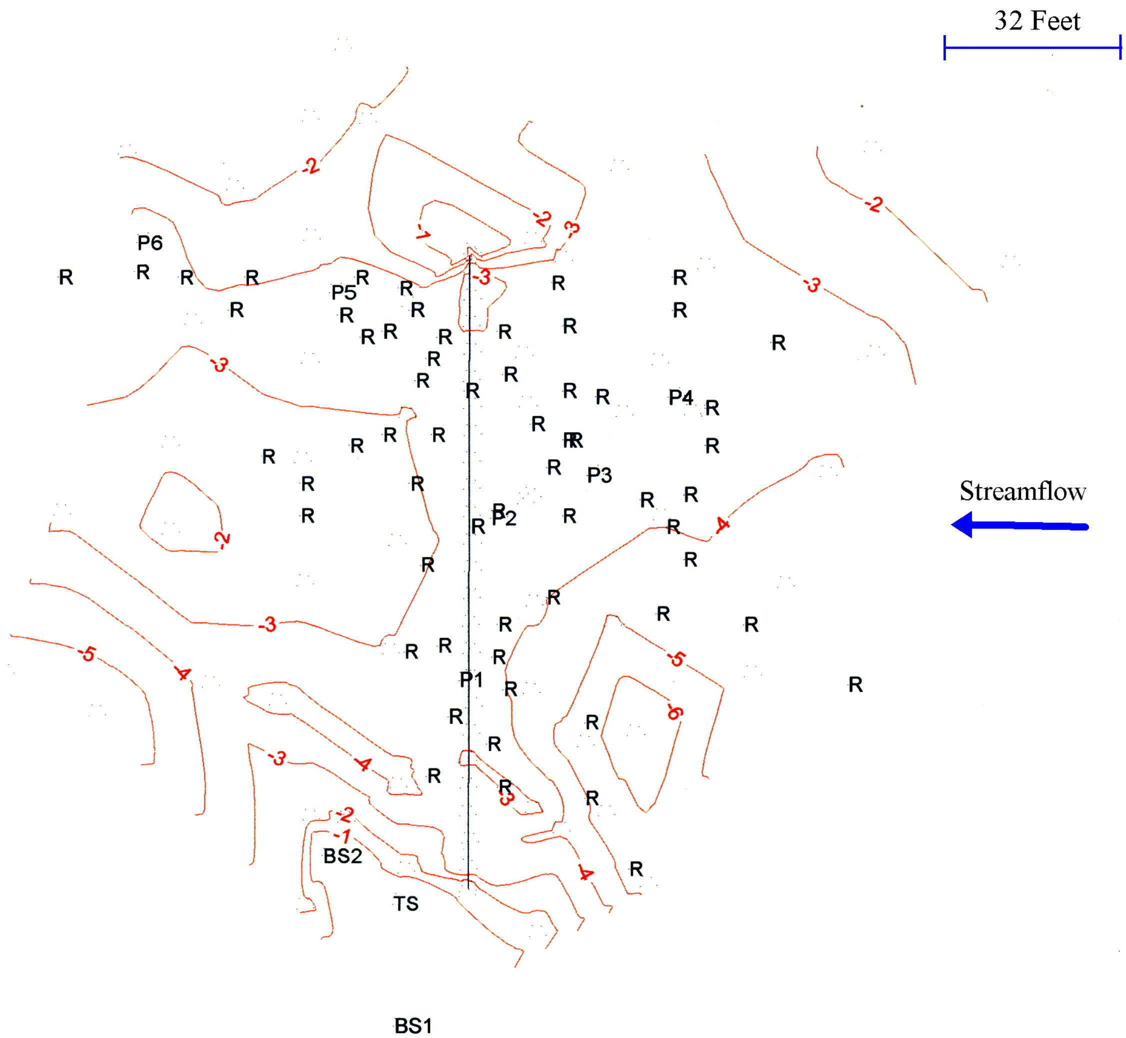


Figure 10. Contour map of Riffle R14 at rivermile 52.6 on the Stanislaus River on 12 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -1.615 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is -0.735 feet and at backsight 2 (BS2) is 0.53 feet.

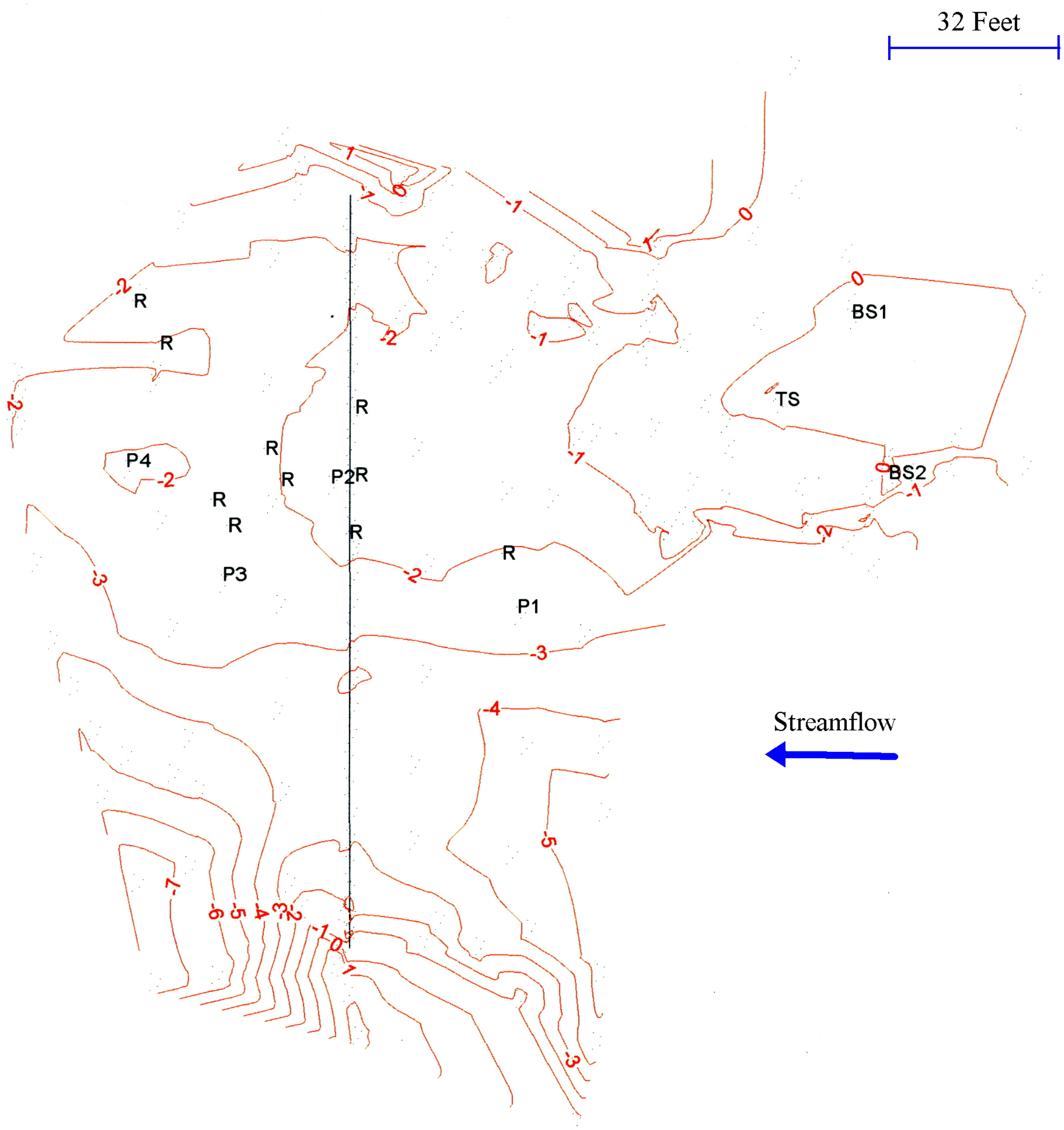


Figure 11. Contour map of Riffle R14A at rivermile 52.57 on the Stanislaus River on 13 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P4). The water surface elevation was -1.265 feet at the transect. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.465 feet and at backsight 2 (BS2) is 0.56 feet.

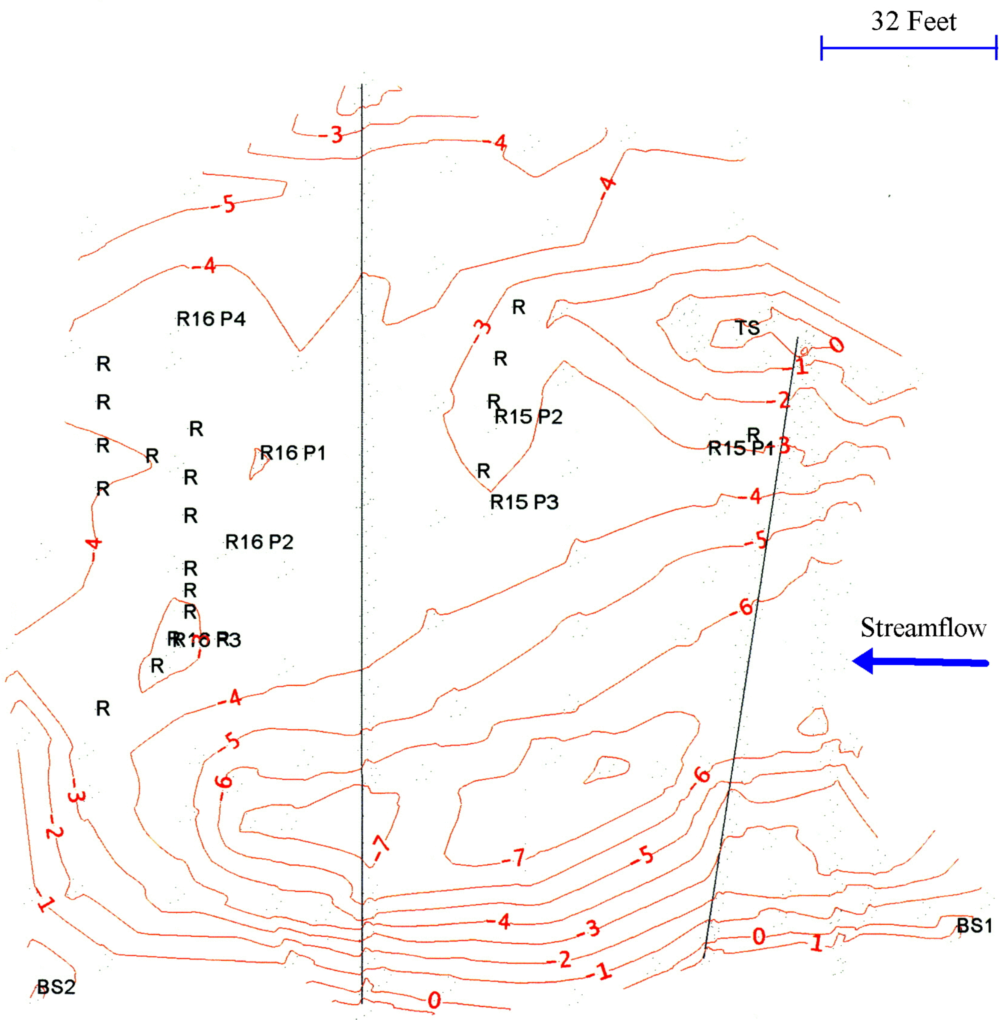


Figure 12. Contour map of riffles R15 and R16 at rivermile 52.5 on the Stanislaus River on 10 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transects (vertical lines), total station (TS), and the standpipes and substrate bulk samples (P1 through P3 for R15 and P1 through P4 for R16). The water surface elevations were -0.665 feet and -0.735 at the transects of riffles R15 and R16 respectively. The elevation of the top of the metal pin at backsight 1 (BS1) is 4.155 feet and at backsight 2 (BS2) is 1.13 feet.

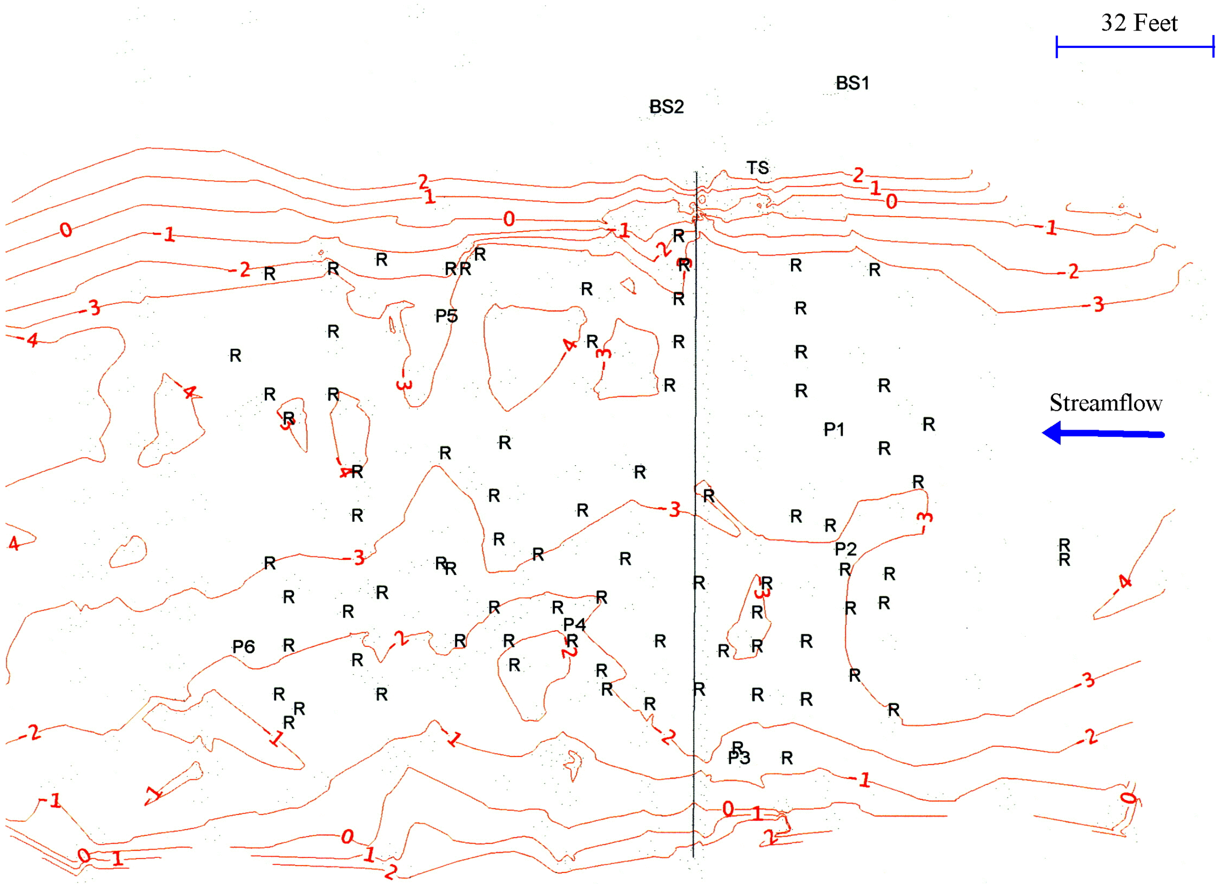


Figure 13. Contour map of Riffle R19 at rivermile 52.13 on the Stanislaus River on 13 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -0.675 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 9.04 feet and at backsight 2 (BS2) is 6.755 feet.

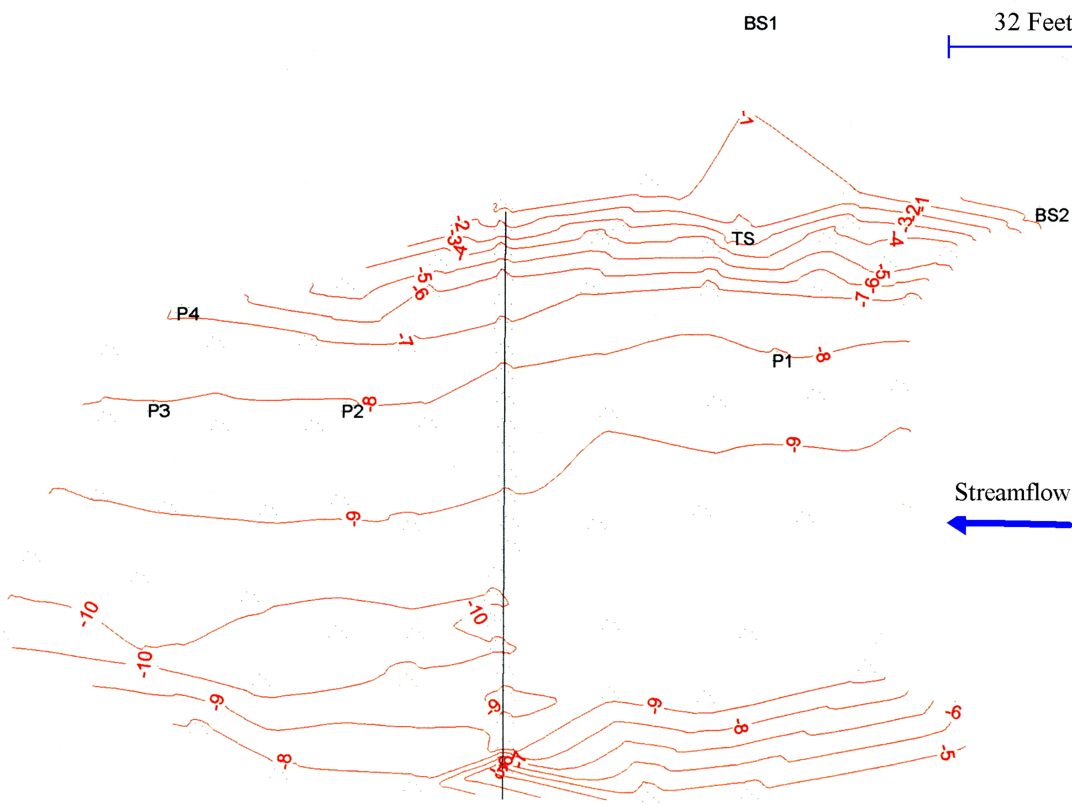


Figure 14. Contour map of Riffle R19A at rivermile 52.06 on the Stanislaus River on 18 August 1999, which was prior to gravel addition. The map shows the locations the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P4). The water surface elevation was -4.36 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is -0.125 feet and at backsight 2 (BS2) is 0.71 feet.

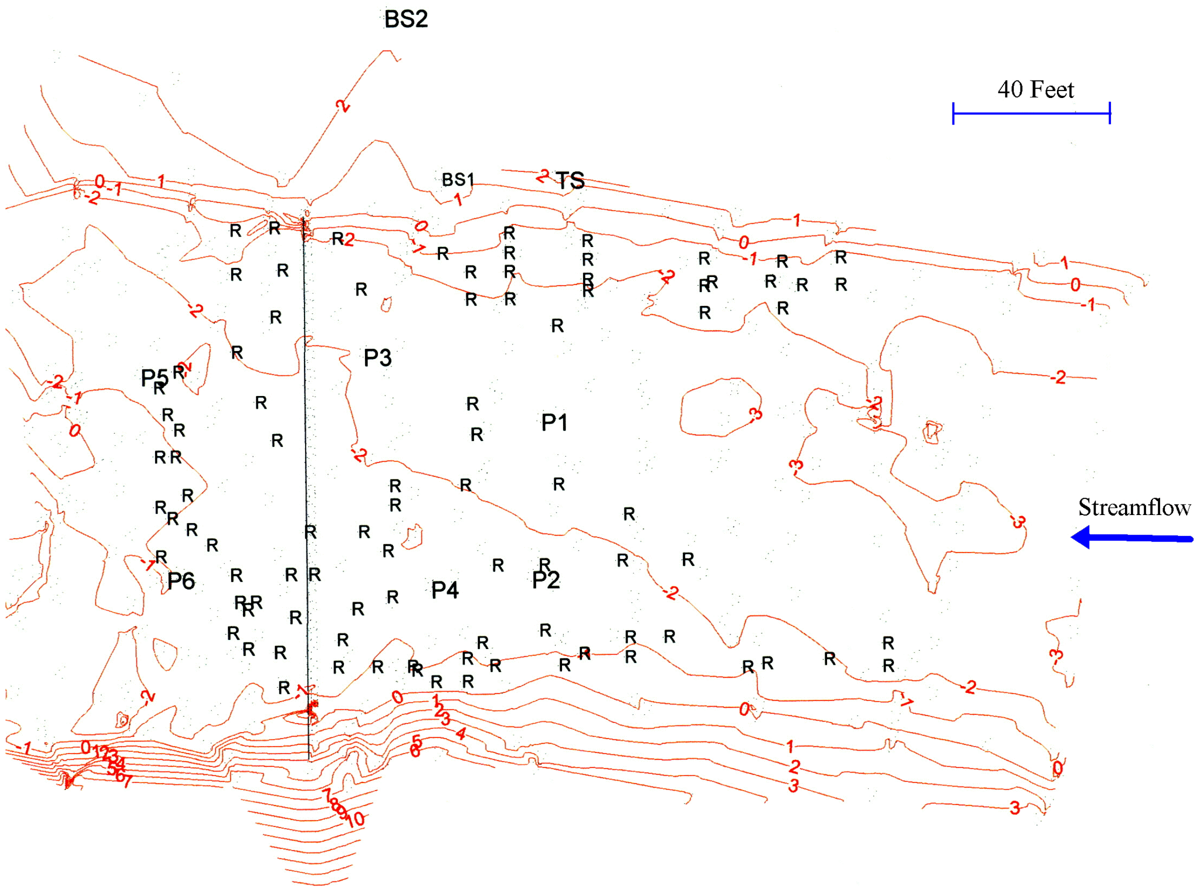


Figure 15. Contour map of Riffle R20 at rivermile 51.8 on the Stanislaus River on 18 August 1999. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was 0.19 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.605 feet and at backsight 2 (BS2) is 2.121 feet.

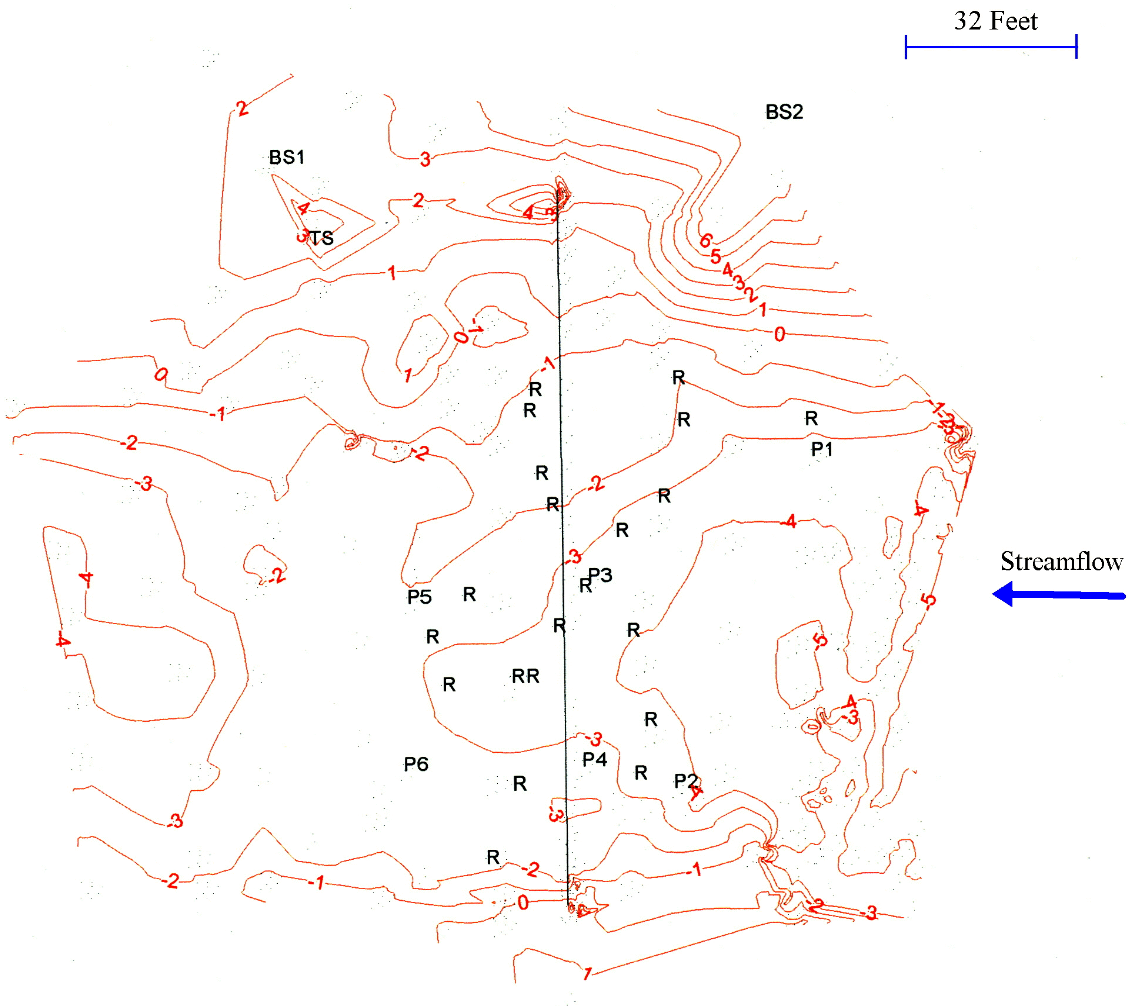


Figure 16. Contour map of Riffle R27 at rivermile 50.8 on the Stanislaus River on 20 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -0.54 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 2.95 feet and at backsight 2 (BS2) was 7.21 feet. BS2 was disturbed and has been replaced.

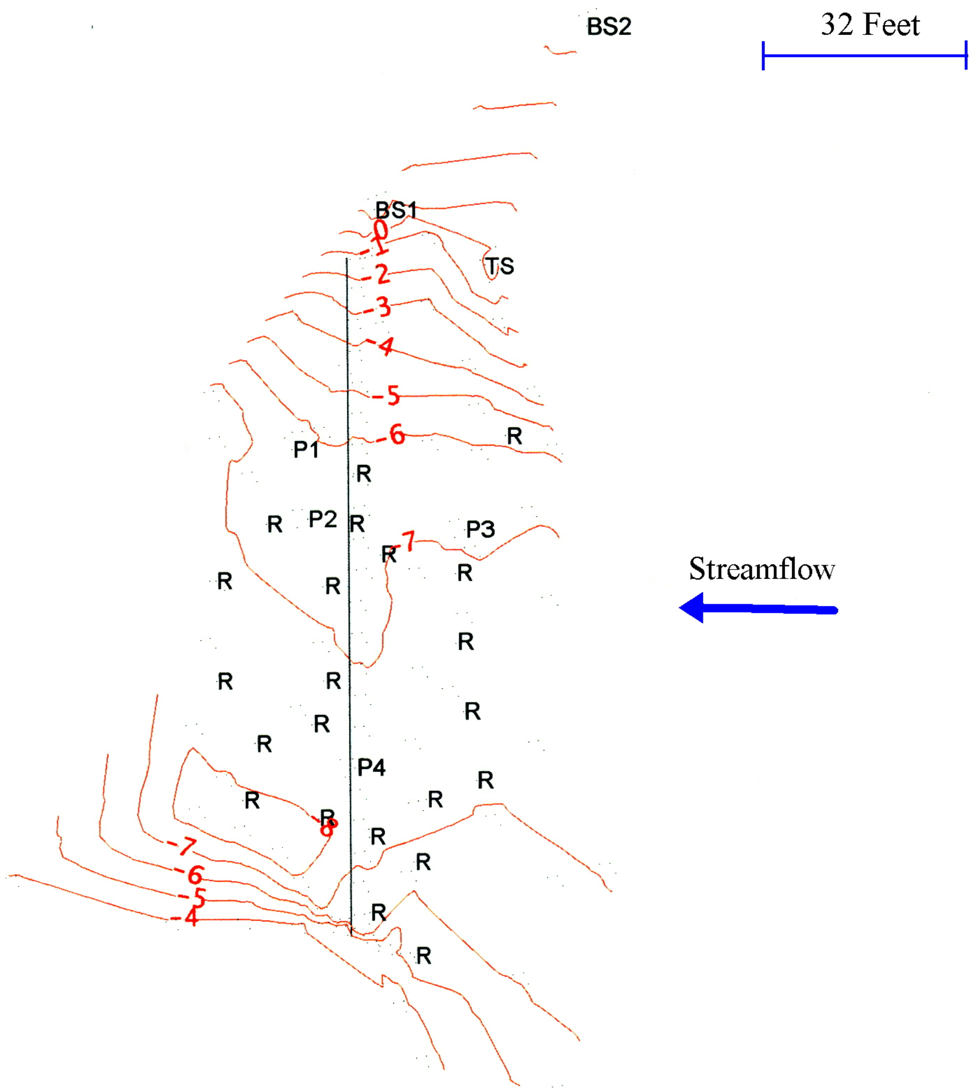


Figure 17. Contour map of Riffle R28A at rivermile 50.2 on 6 August 1999. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P4). The water surface elevation was -3.90 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.52 feet and at backsight 2 (BS2) was 4.495 feet. BS2 was disturbed and has been replaced.

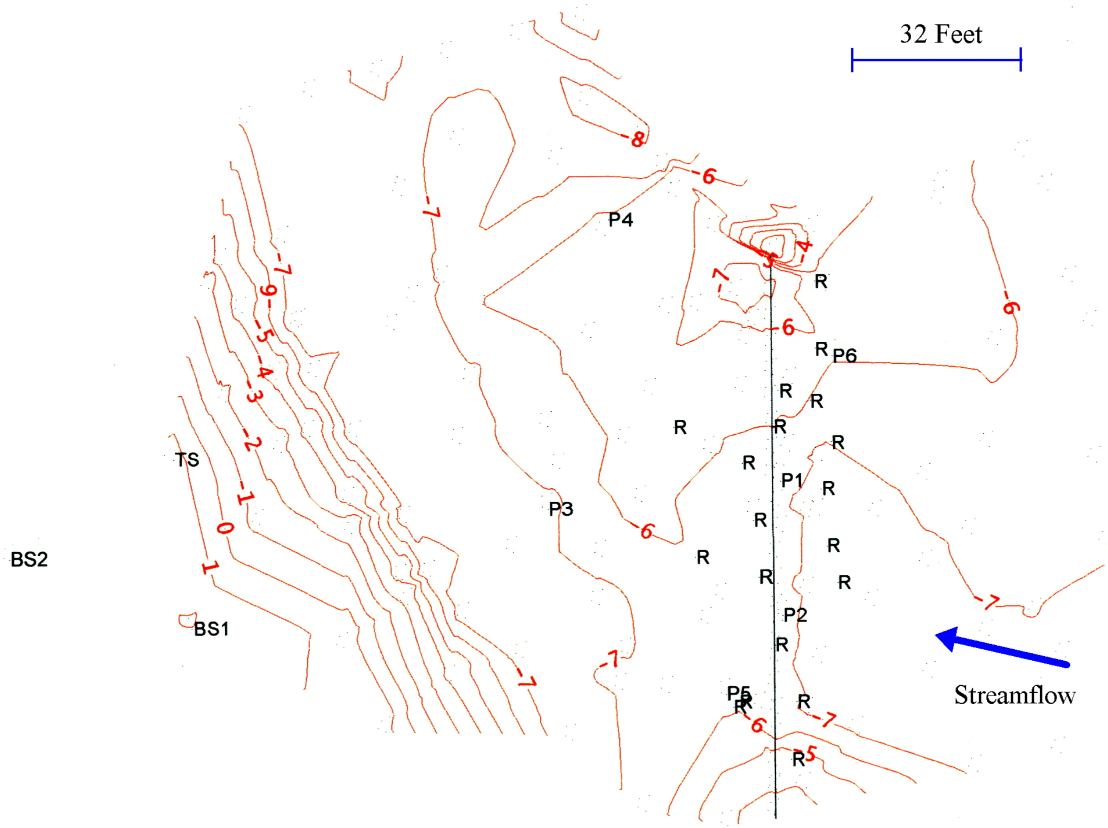


Figure 18. Contour map of Riffle R29 at rivermile 49.75 on the Stanislaus River on 9 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -4.135 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.995 feet and at backsight 2 (BS2) is 1.88 feet.

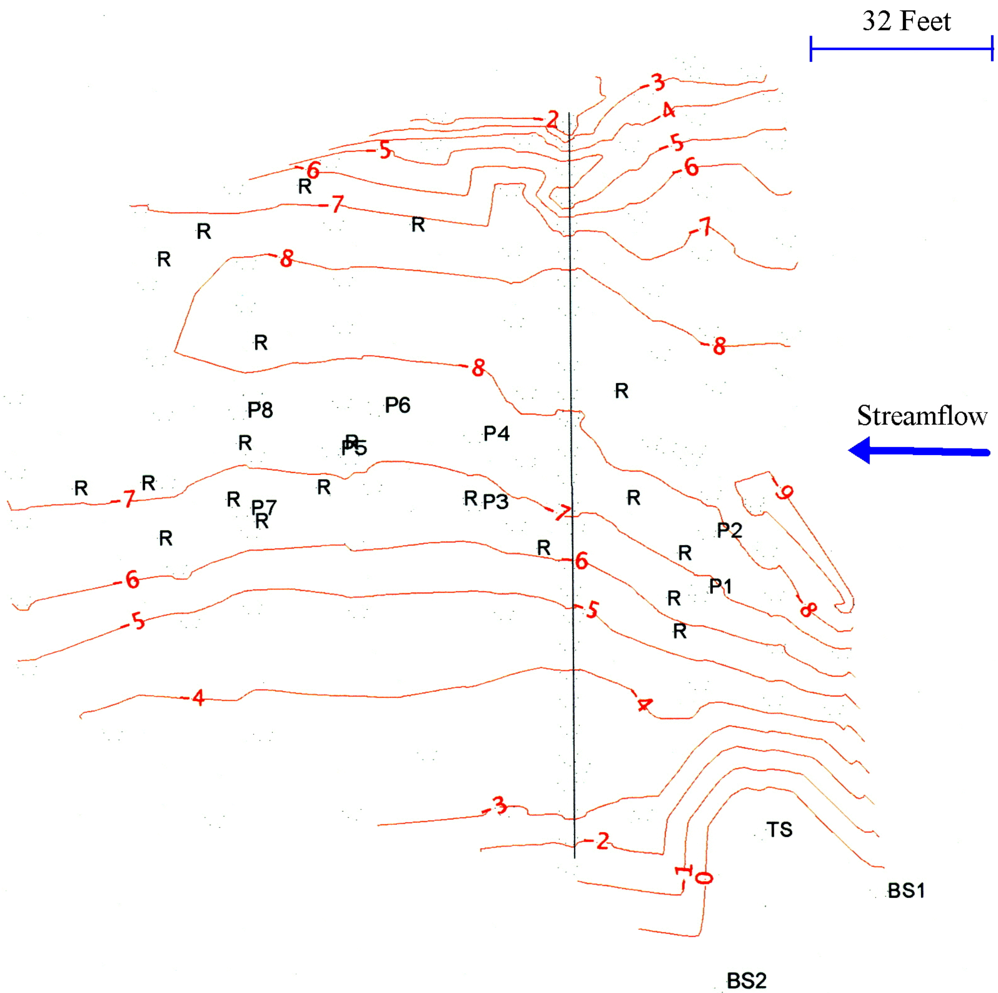


Figure 19. Contour map of Riffle R43 at rivermile 46.9 on the Stanislaus River on 2 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P8). The water surface elevation was -4.74 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 0.70 feet and at backsight 2 (BS2) is 1.245 feet.

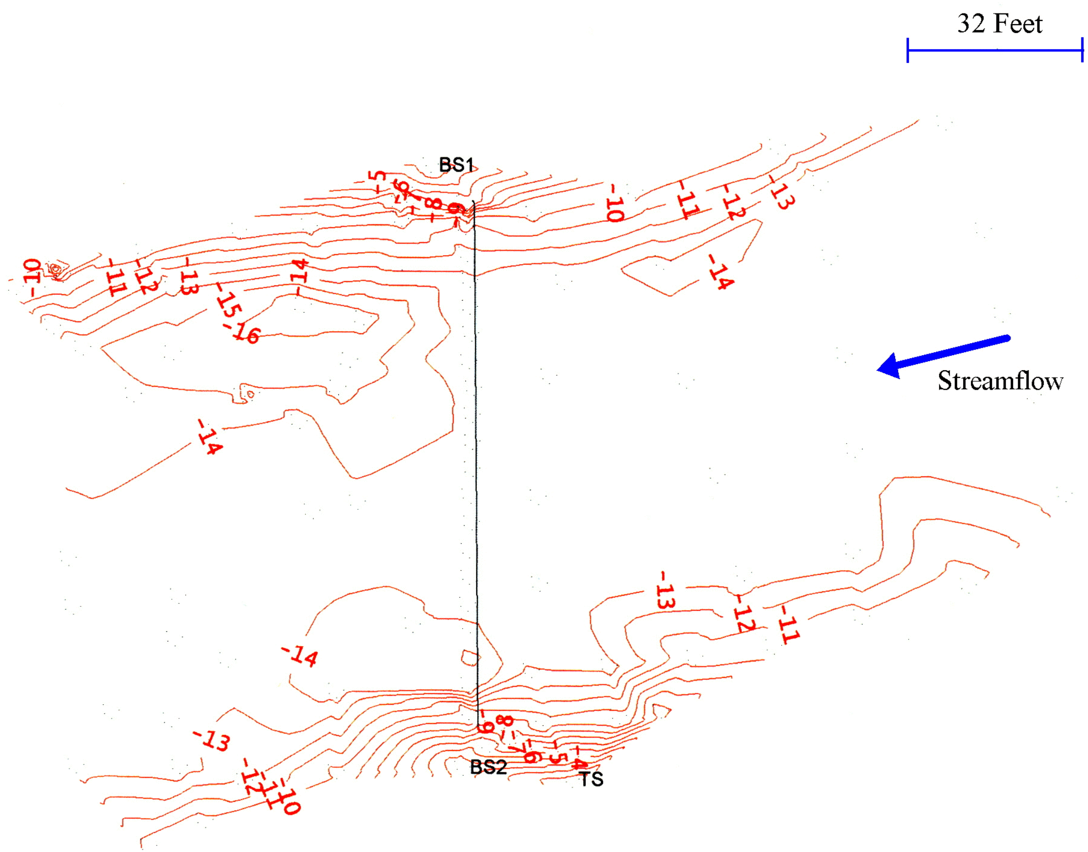


Figure 20. Contour map of Riffle R57 at rivermile 44.6 on the Stanislaus River on 17 August 1999, which was prior to gravel addition. The map shows the locations of the transect (vertical line) and total station (TS). The water surface elevation was -9.78 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is -2.20 feet and at backsight 2 (BS2) is -3.325 feet. No substrate or intragravel water quality samples were collected at this site.

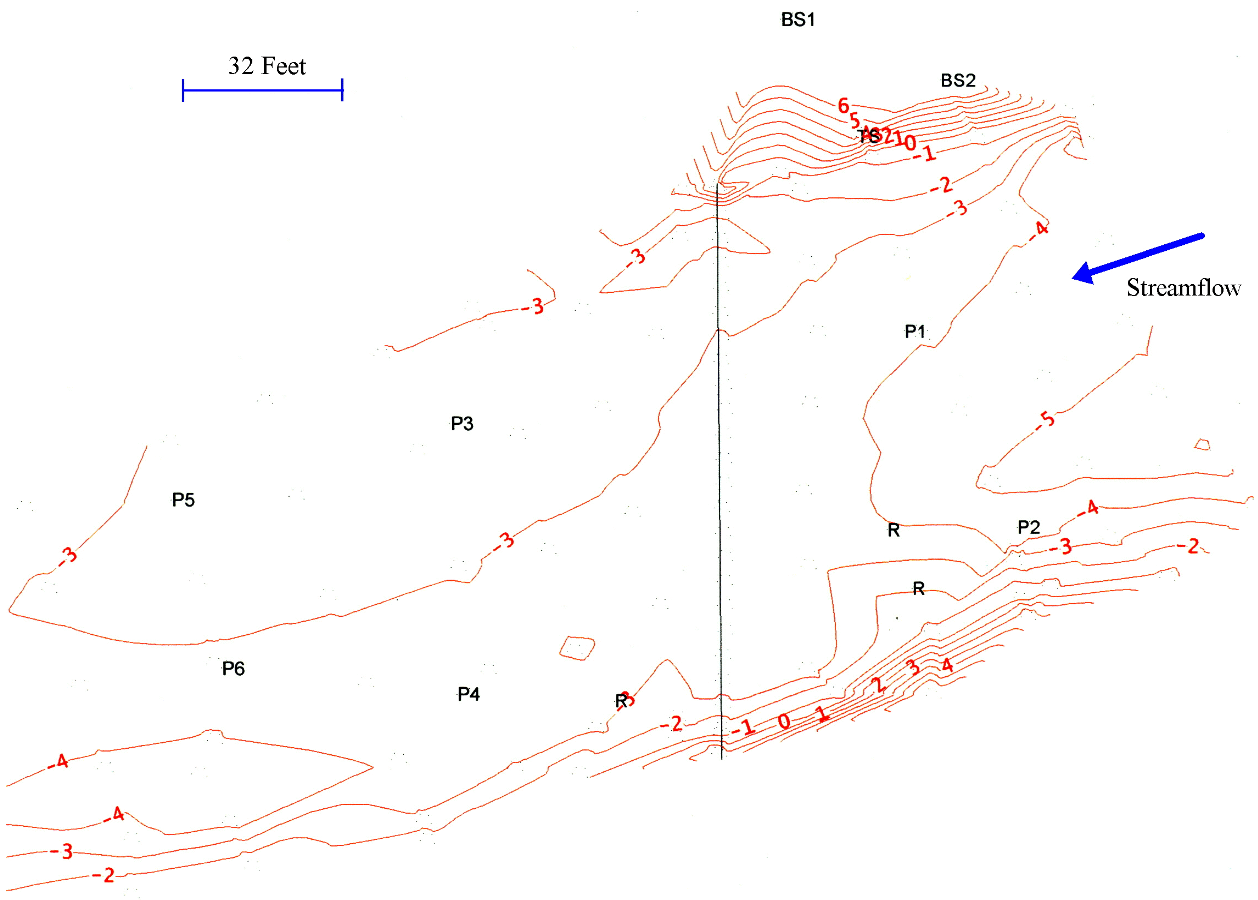


Figure 21. Contour map of Riffle R58 at rivermile 44.5 on the Stanislaus River on 2 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -0.955 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 11.45 feet and at backsight 2 (BS2) is 7.00 feet.

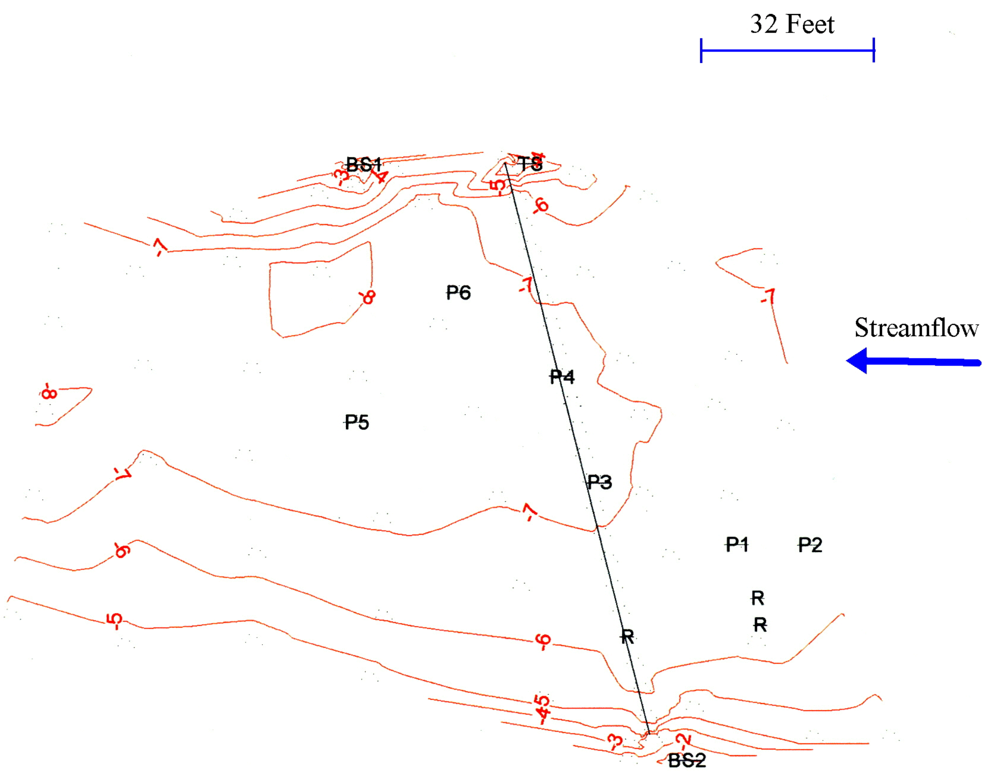


Figure 22. Contour map of Riffle R59 at rivermile 44.4 on the Stanislaus River on 20 August 1999. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was -4.435 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is -1.635 feet and at backsight 2 (BS2) was -0.685 feet. BS2 was disturbed and has been replaced.

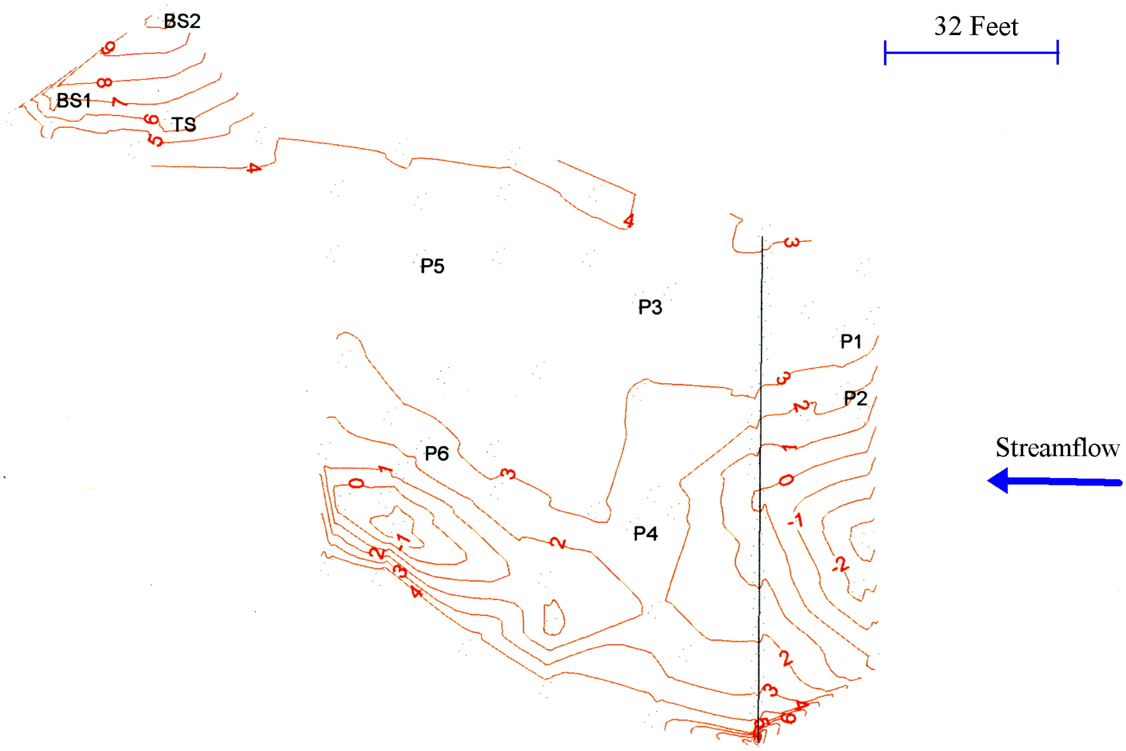


Figure 23. Contour map of Riffle R76 at rivermile 40.35 on the Stanislaus River on 19 August 1999. The map shows the locations of the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P6). The water surface elevation was 5.475 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 8.065 feet and at backsight 2 (BS2) was 10.295 feet.

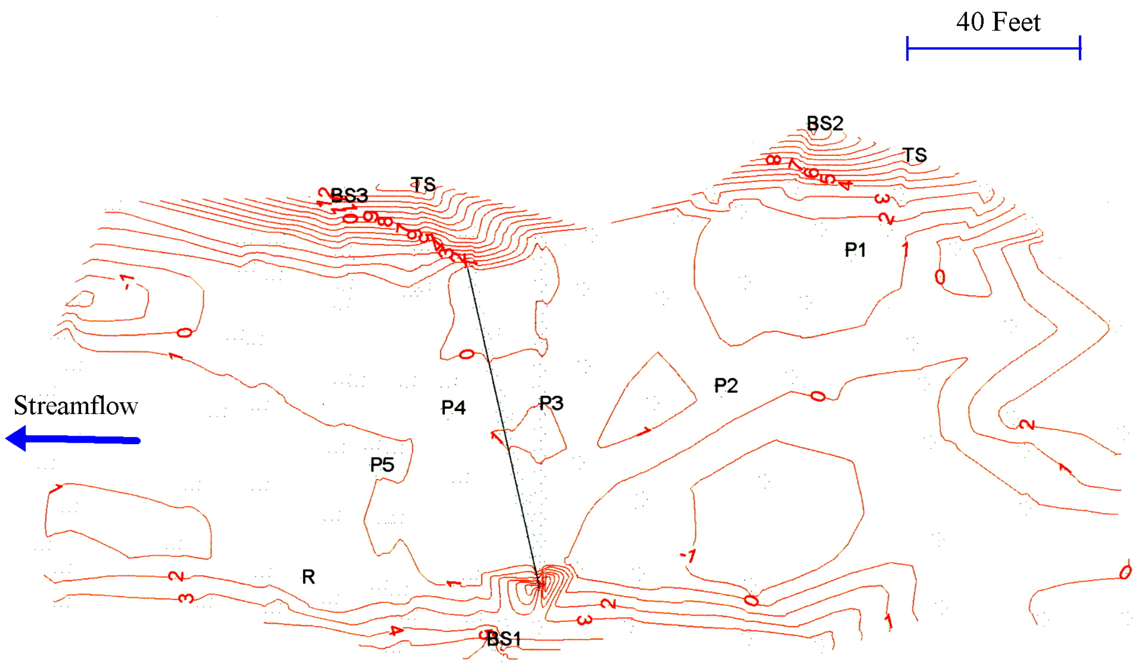


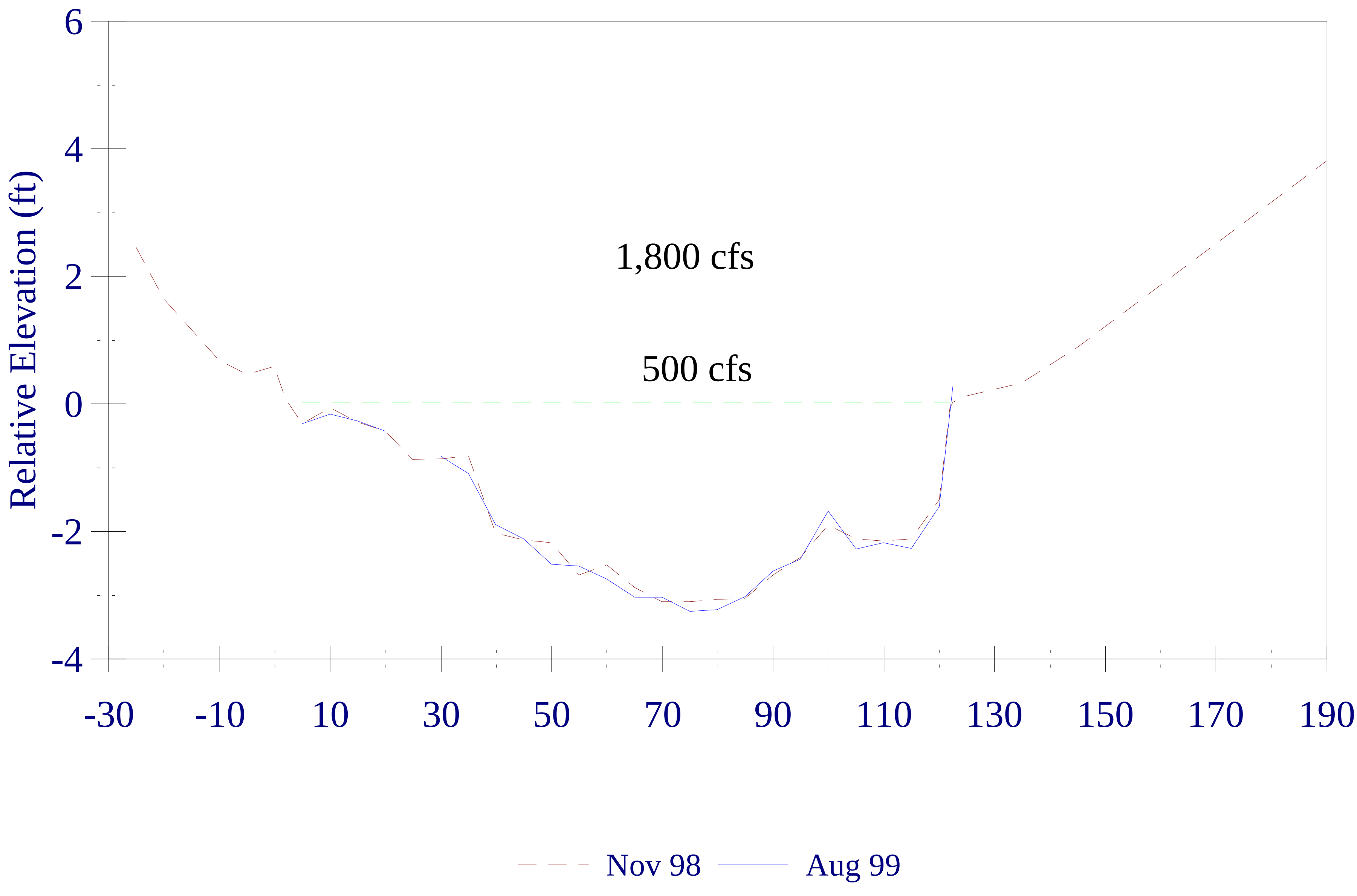
Figure 24. Contour map of Riffle R78 at rivermile 40.2 on the Stanislaus River on 16 August 1999, which was prior to gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), total station (TS), and the standpipes and substrate bulk samples (P1 through P5). The water surface elevation was 3.22 feet at the transect. The elevation of the top of the metal pins at backsight 1 (BS1) is 6.00 feet, backsight 2 (BS2) is 14.025, and at backsight 3 (BS3) is 13.07 feet.

APPENDIX 4

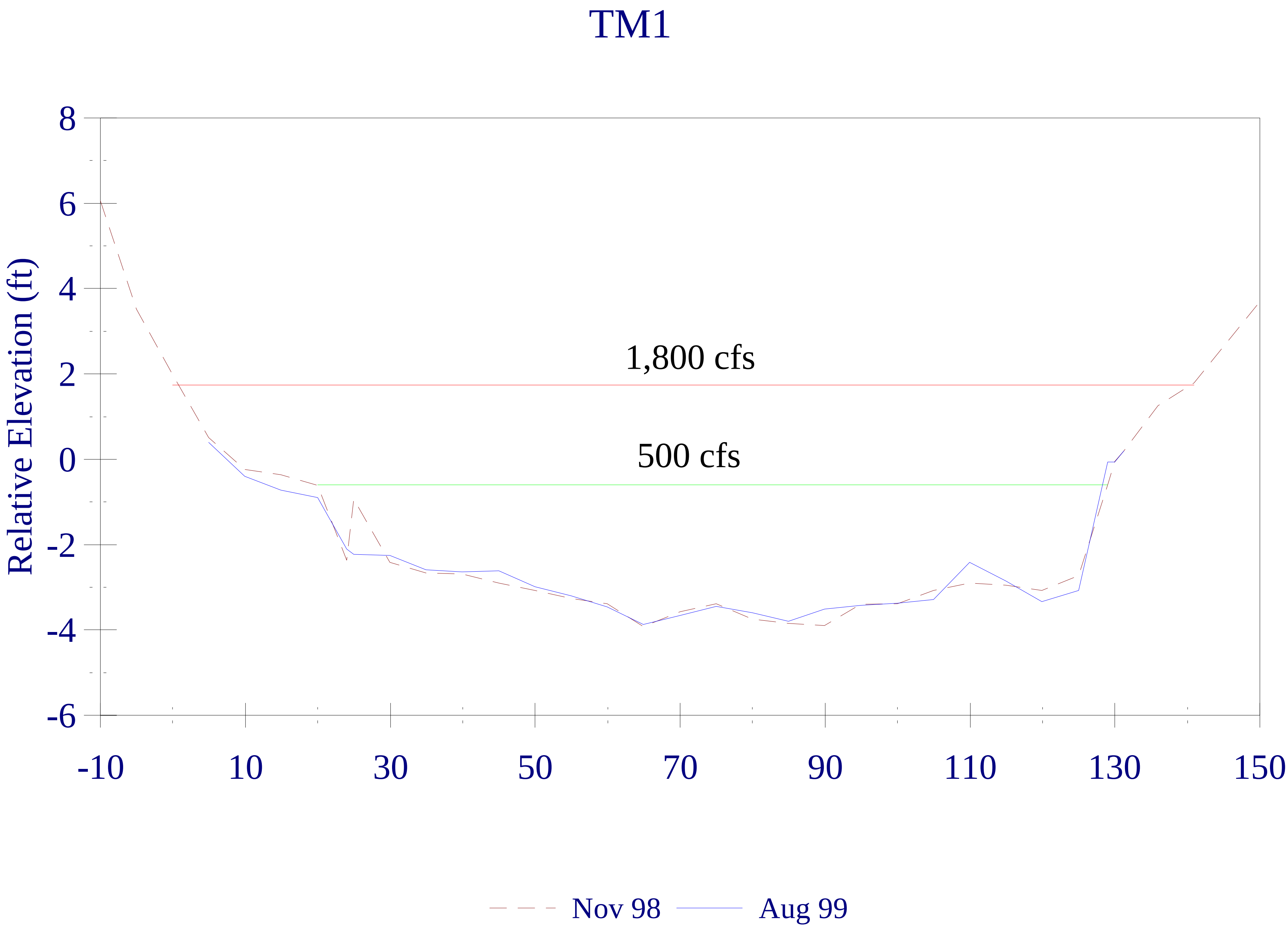
Figures of Pre-Project Streambed and Water Surface Elevations

The relative streambed and water surface elevations were measured at a single transect prior to restoration in November 1998 and again in August 1999 at each of the 25 study riffles. The water surface elevation at a flow of 500 cfs was measured in November 1998 and the water surface elevation at a flow of about 1,800 cfs was marked on 17 and 18 October 1998 with at wooden stake at the water's edge and measured in November 1998. The elevations shown in these graphs are comparable to those in the contour maps in Appendix 3.

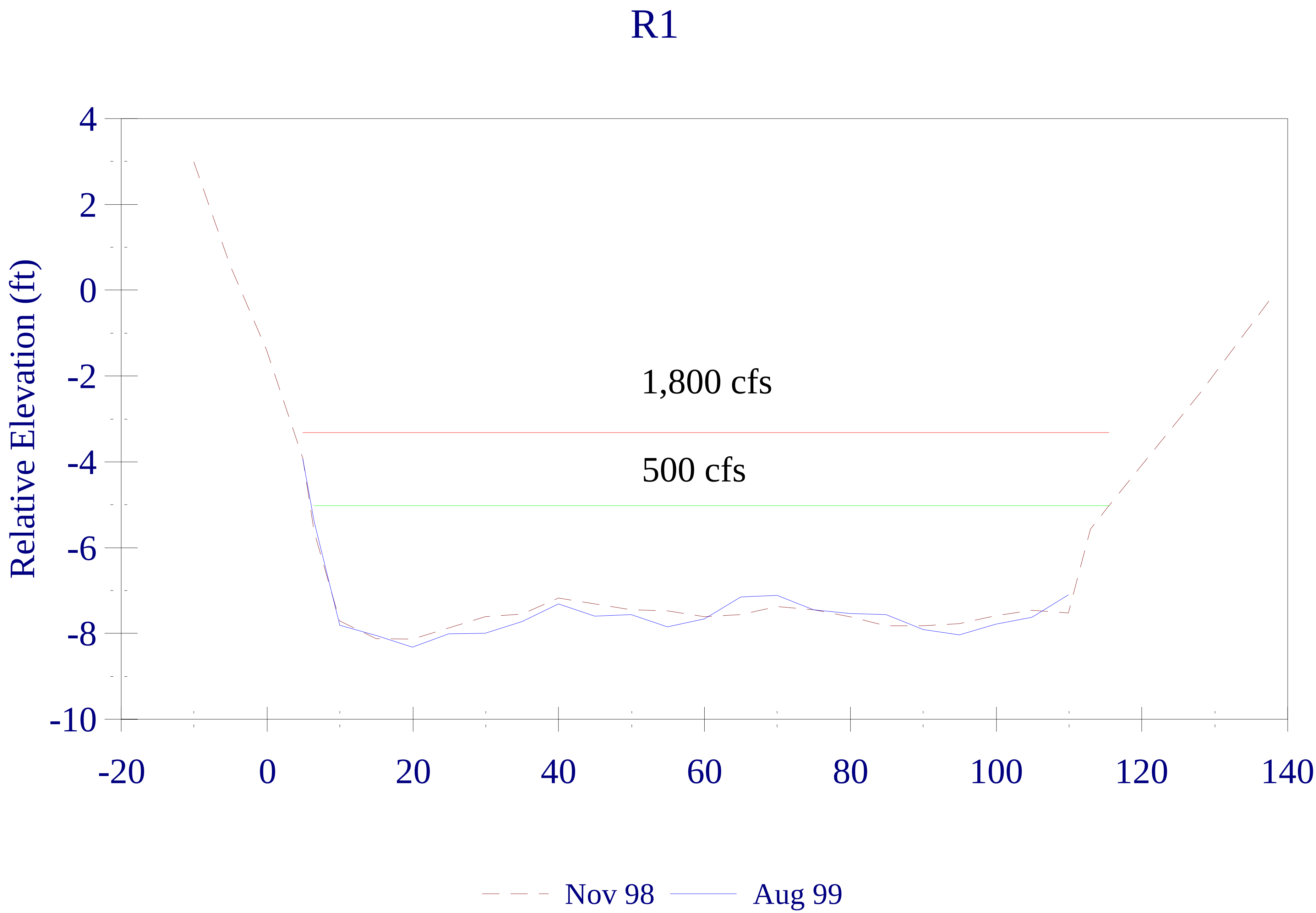
TMA

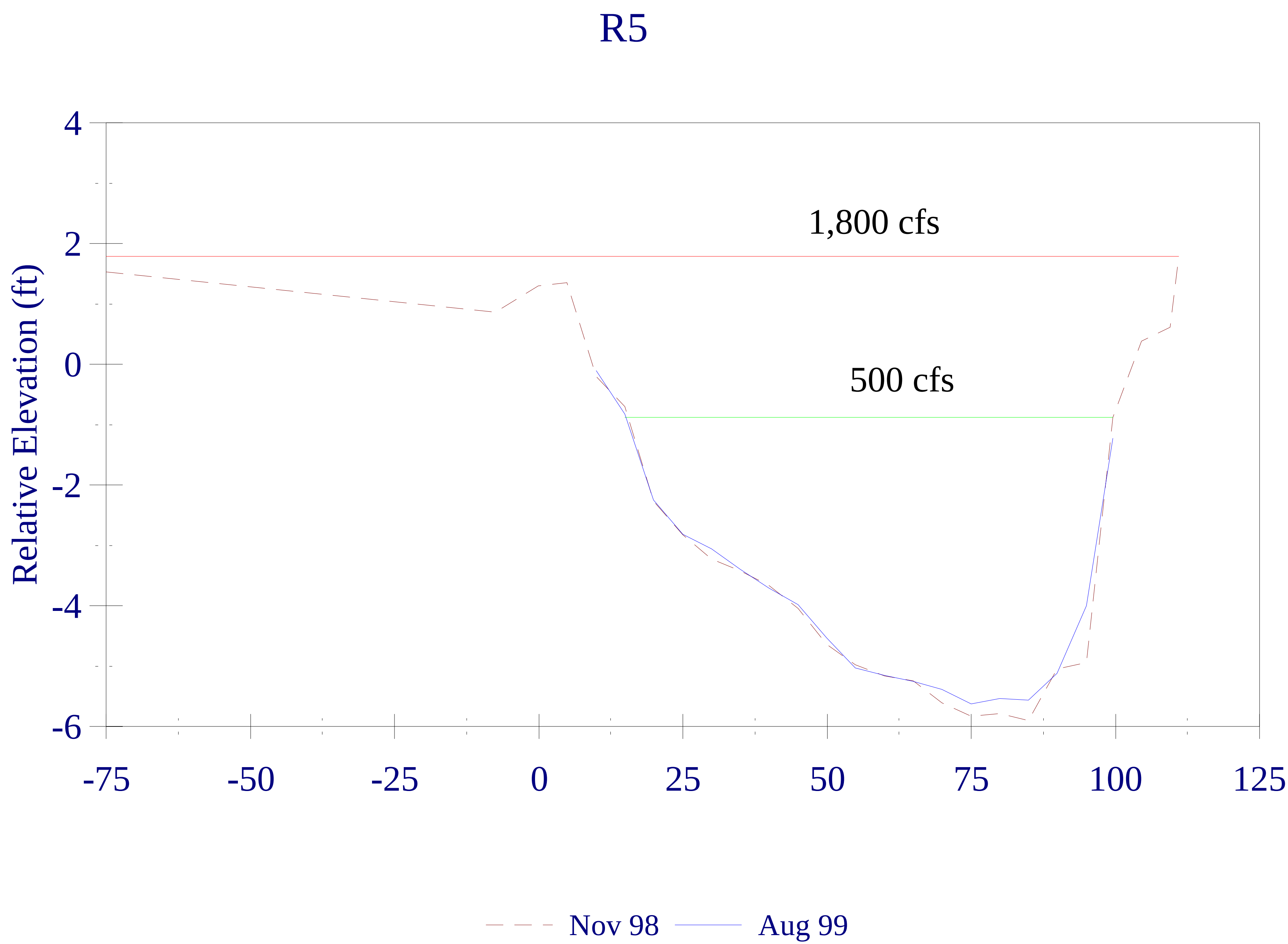


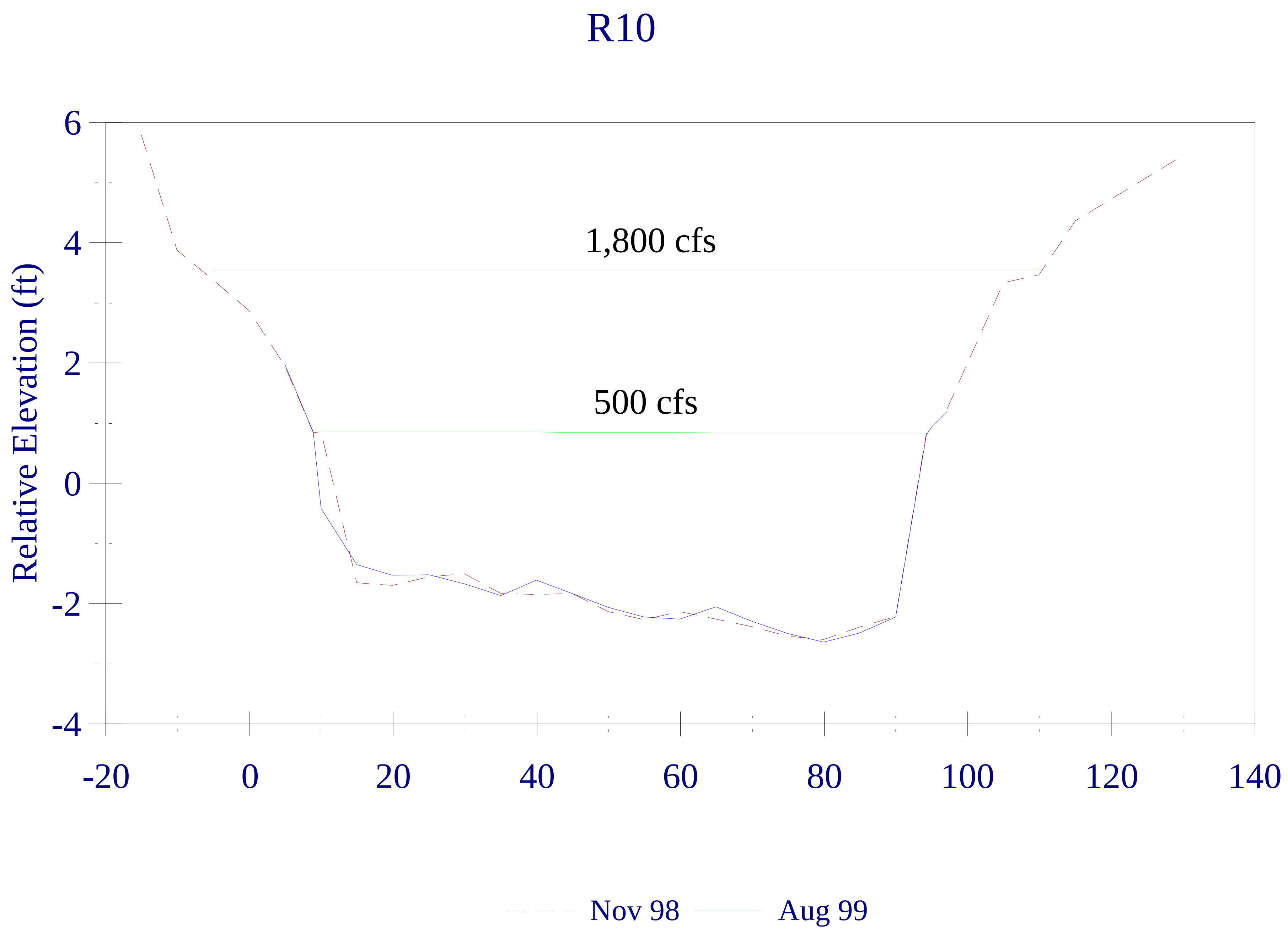
Relative Elevation (ft)
6
4
2
0
-2
-4
-30
-10
10
30
50
70
90
110
130
150
170
190
1,800 cfs
500 cfs
Nov 98
Aug 99



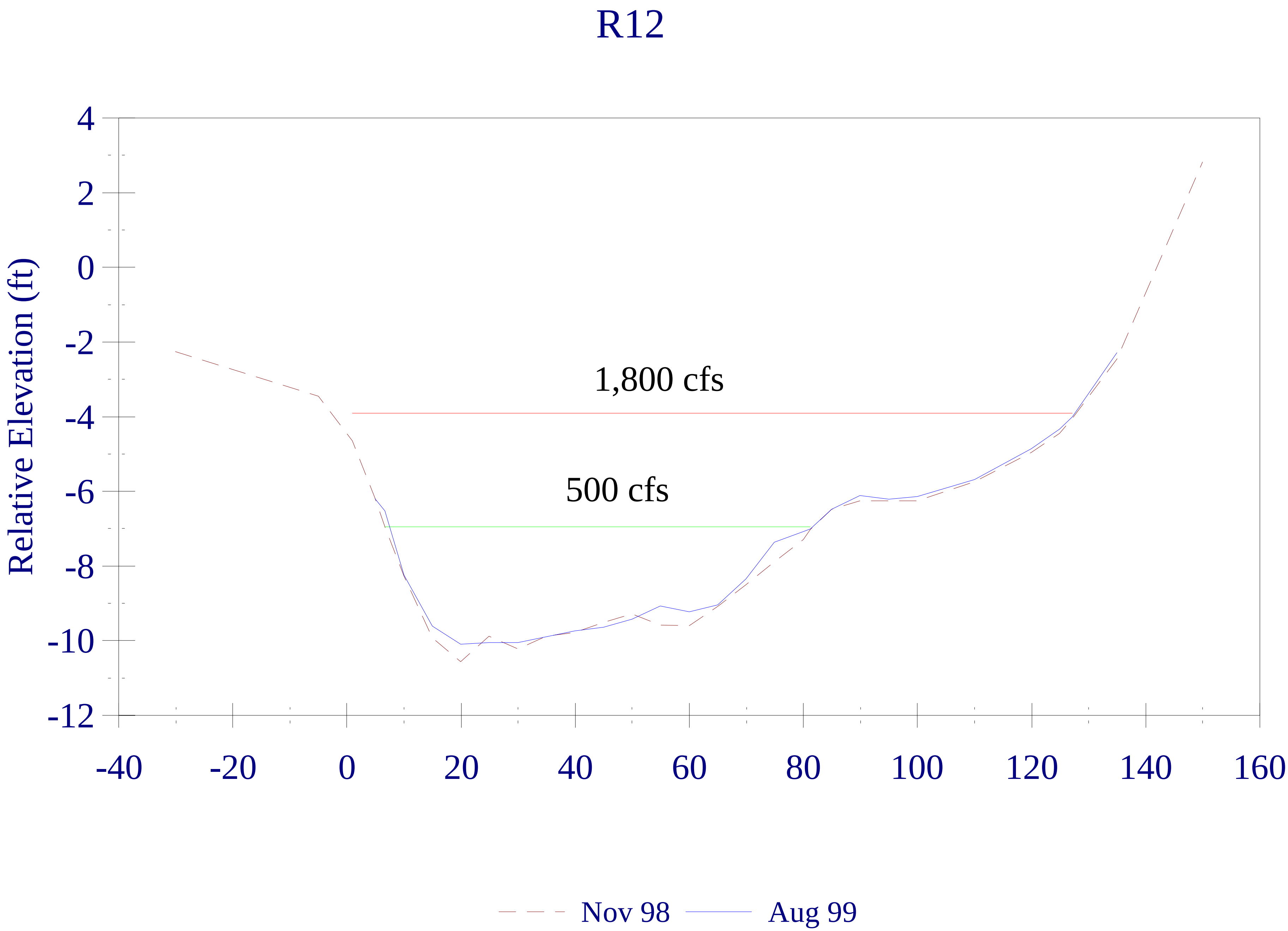
TM1
Relative Elevation (ft)
8
6
4
2
0
-2
-4
-6
-10
10
30
50
70
90
110
130
150
1,800 cfs
500 cfs
Nov 98
Aug 99


R1
Relative Elevation (ft)
4
2
0
-2
-4
-6
-8
-10
-20
0
20
40
60
80
100
120
140
1,800 cfs
500 cfs
Nov 98
Aug 99

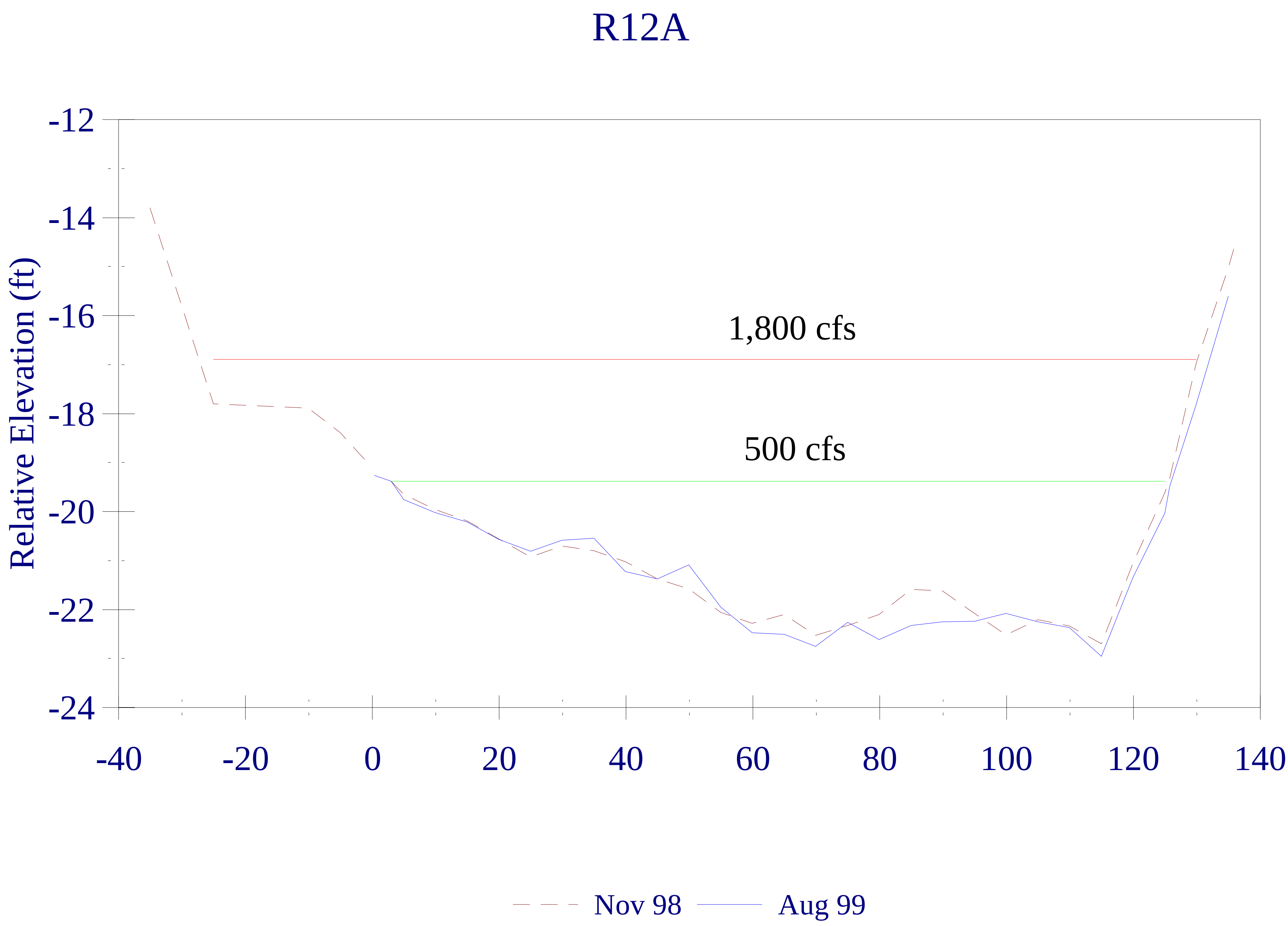

R5
1,800 cfs
500 cfs
Relative Elevation (ft)
4
2
0
-2
-4
-6
-75
-50
-25
0
25
50
75
100
125
Nov 98
Aug 99

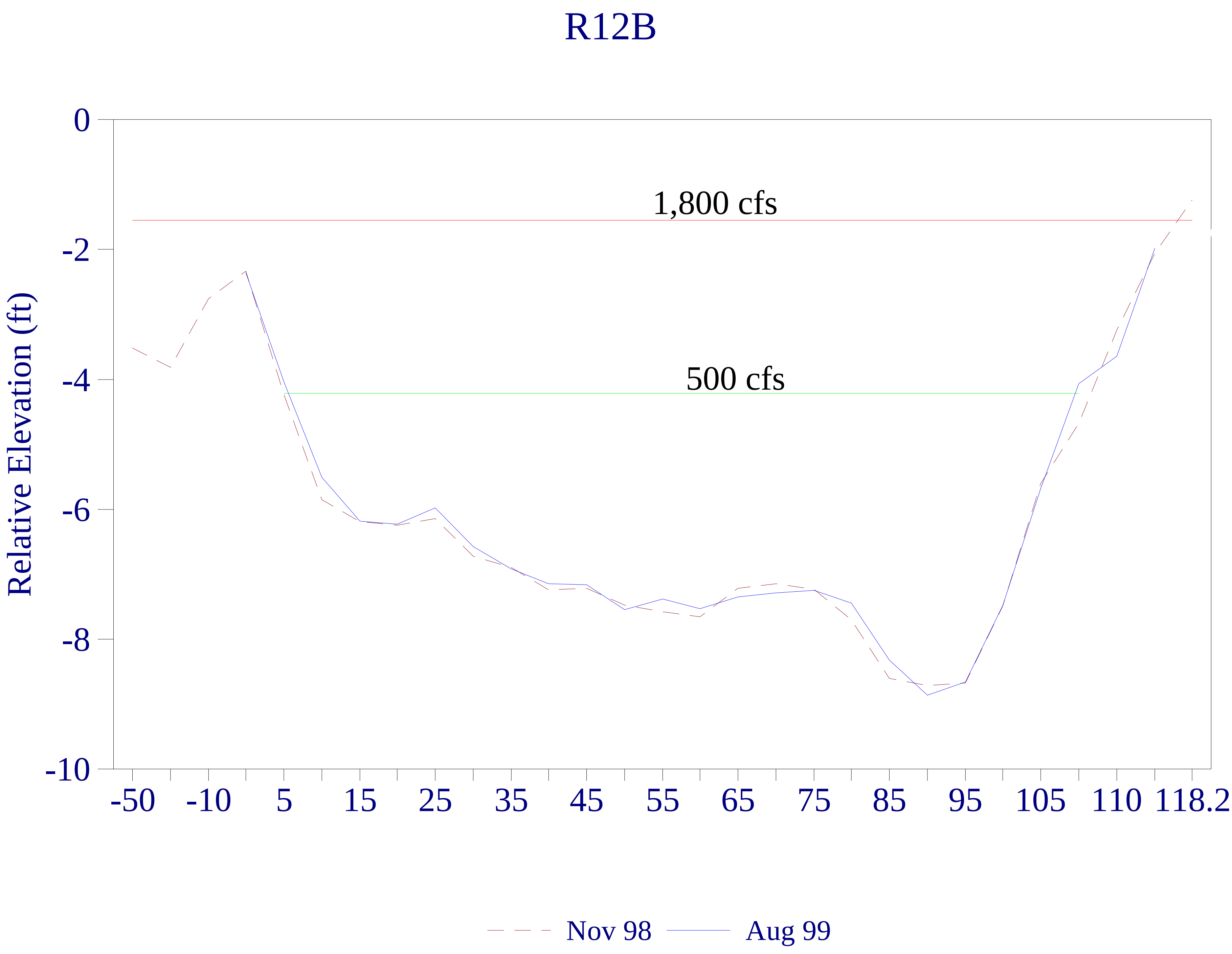


R10
1,800 cfs
500 cfs
Relative Elevation (ft)
6
4
2
0
-2
-4
-20
0
20
40
60
80
100
120
140
Nov 98
Aug 99



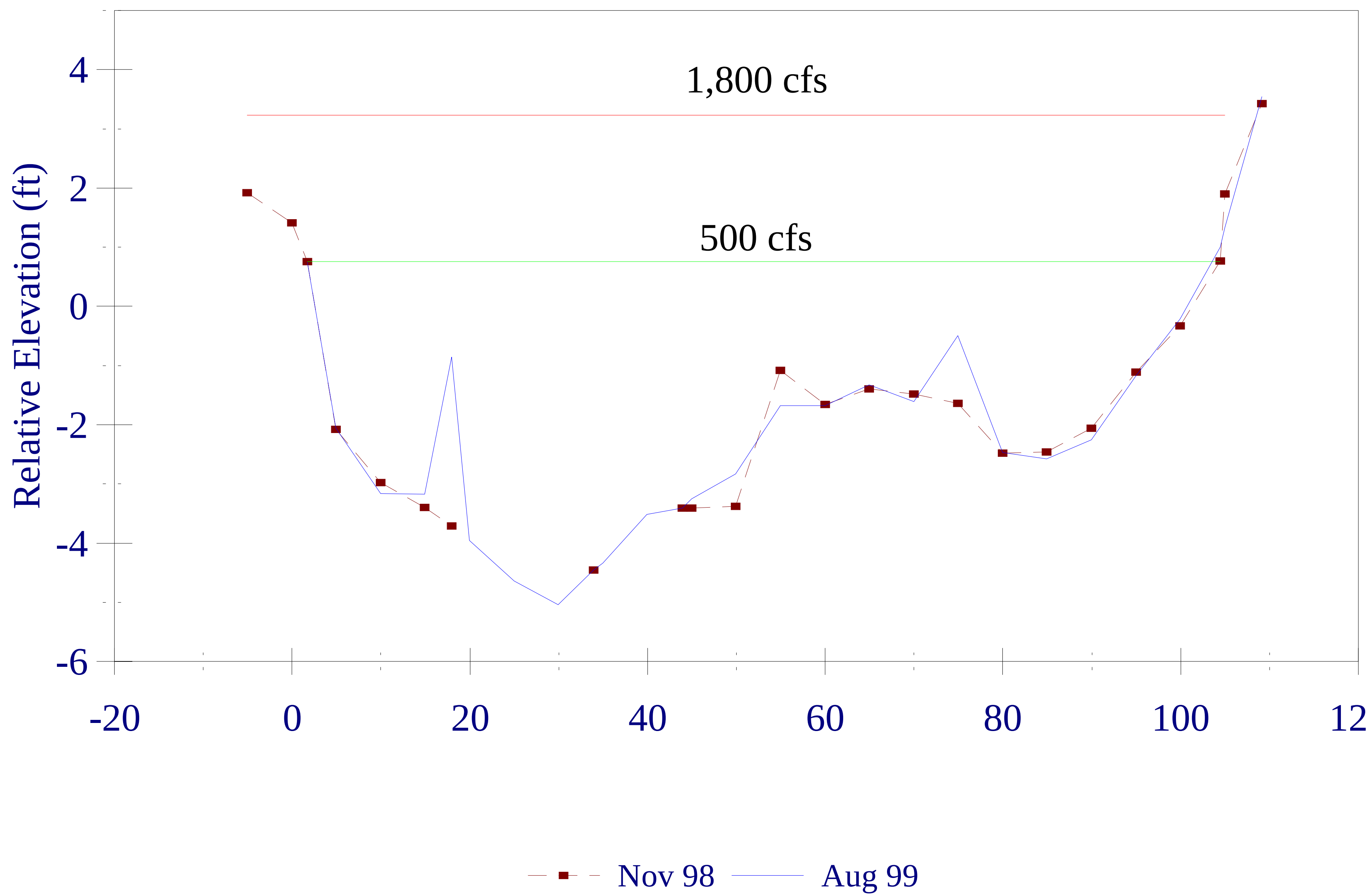
R12
Relative Elevation (ft)
4
2
0
-2
-4
-6
-8
-10
-12
-40
-20
0
20
40
60
80
100
120
140
160
1,800 cfs
500 cfs
Nov 98
Aug 99


R12A
Relative Elevation (ft)
-12
-14
-16
-18
-20
-22
-24
-40
-20
0
20
40
60
80
100
120
140
1,800 cfs
500 cfs
Nov 98
Aug 99

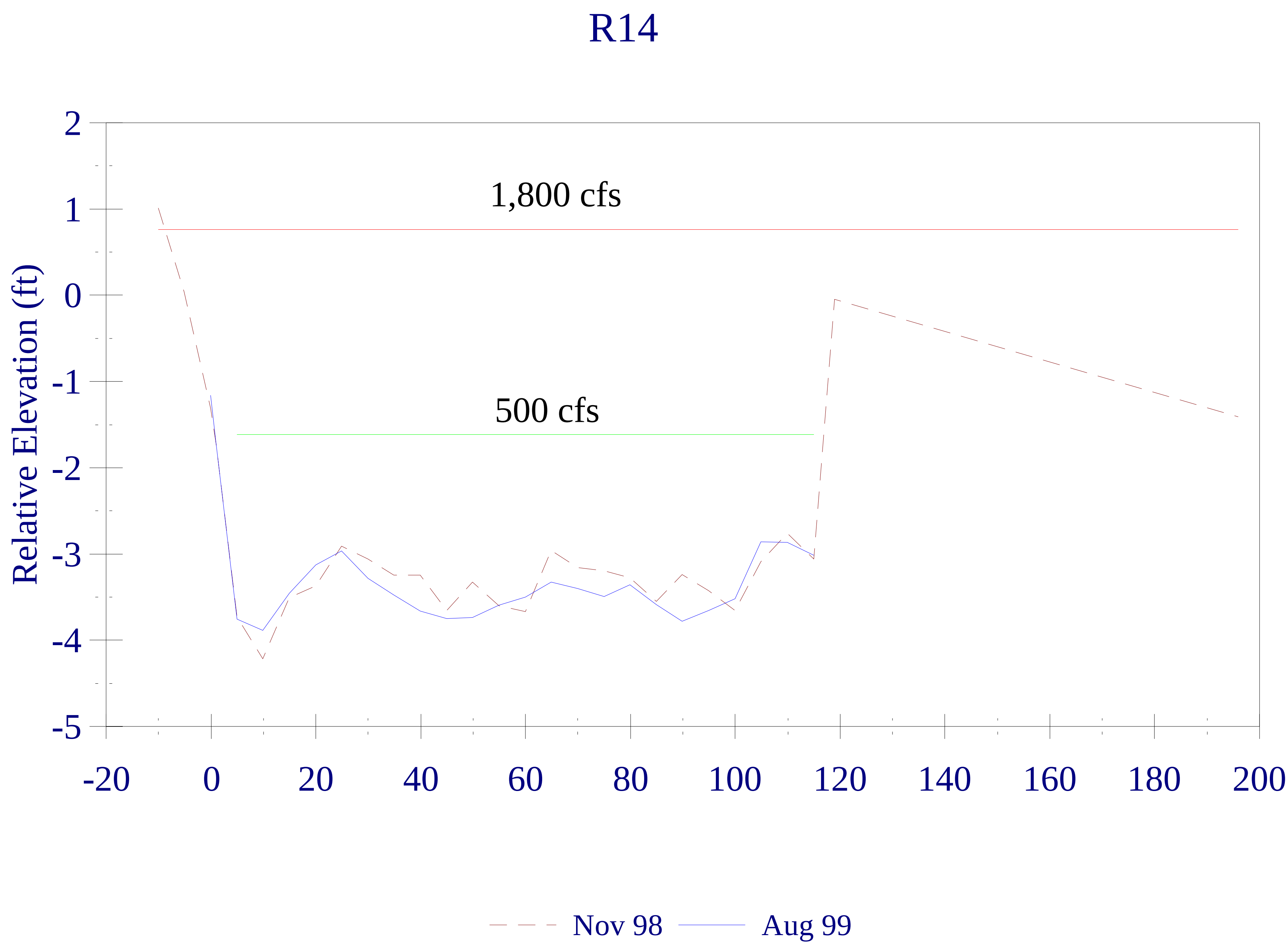


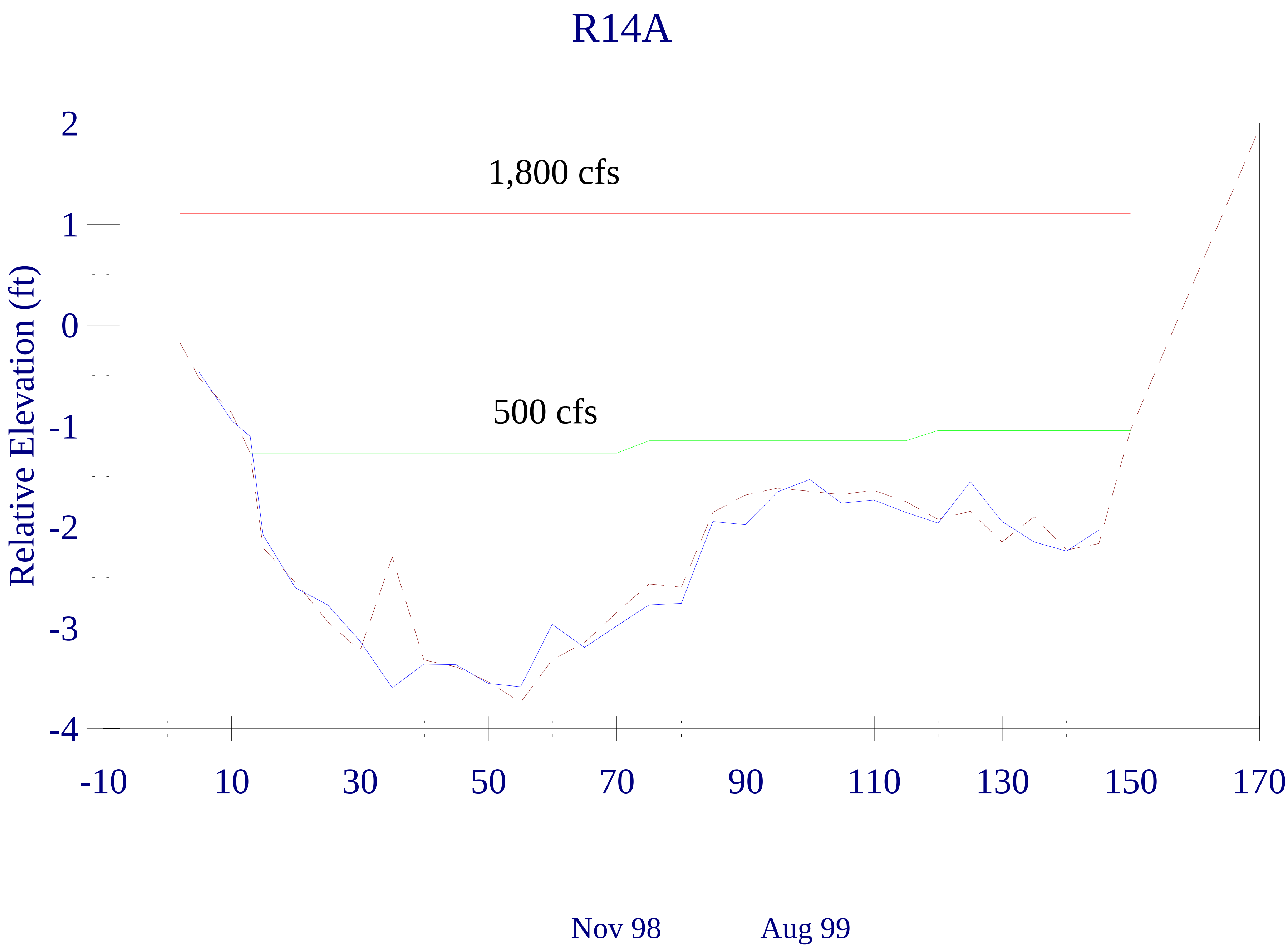
R12B
Relative Elevation (ft)
0
-2
-4
-6
-8
-10
1,800 cfs
500 cfs
-50
-10
5
15
25
35
45
55
65
75
85
95
105
110
118.2
Nov 98
Aug 99

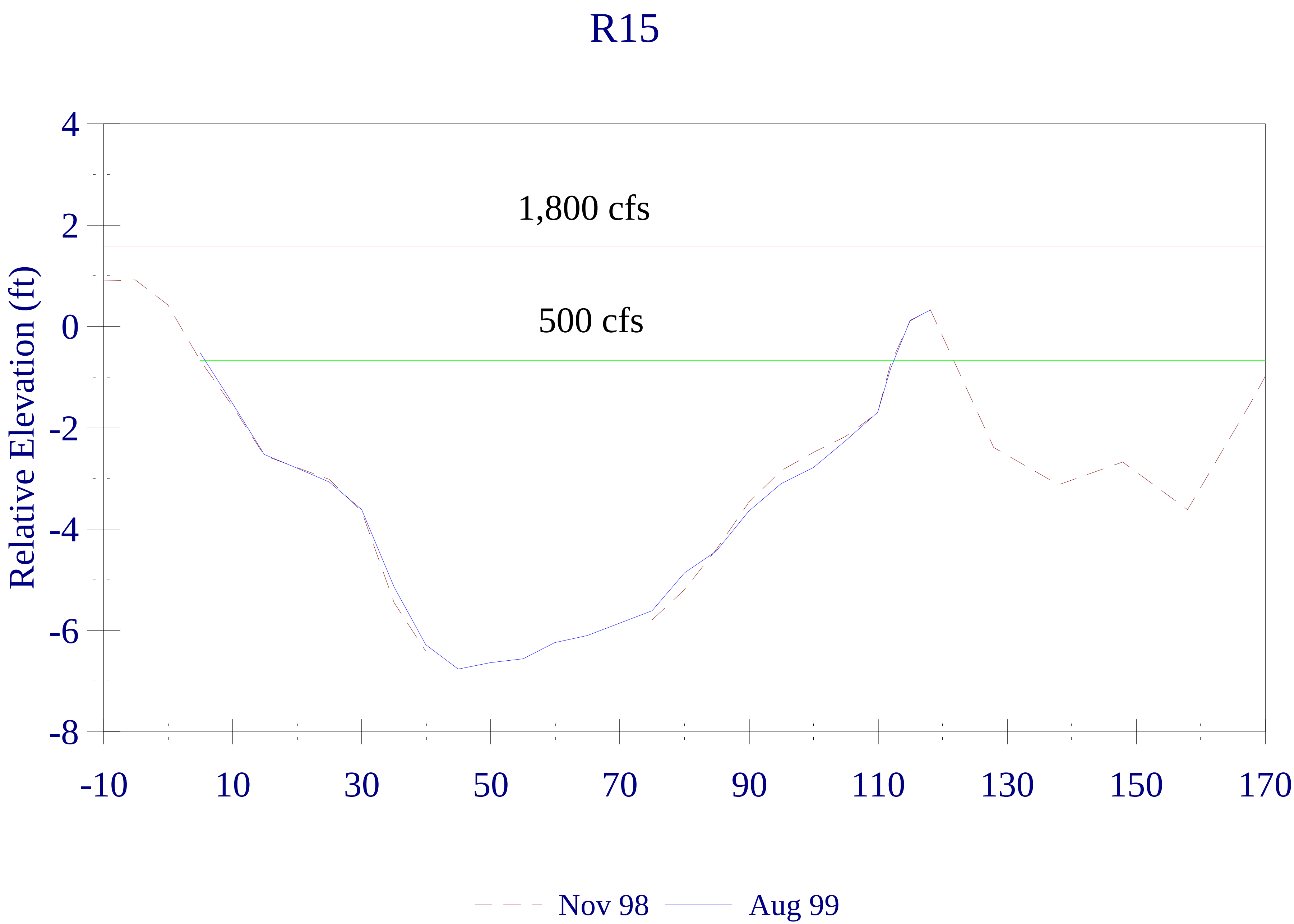
R13



1,800 cfs
500 cfs
Relative Elevation (ft)
4
2
0
-2
-4
-6
-20
0
20
40
60
80
100
120
Nov 98
Aug 99

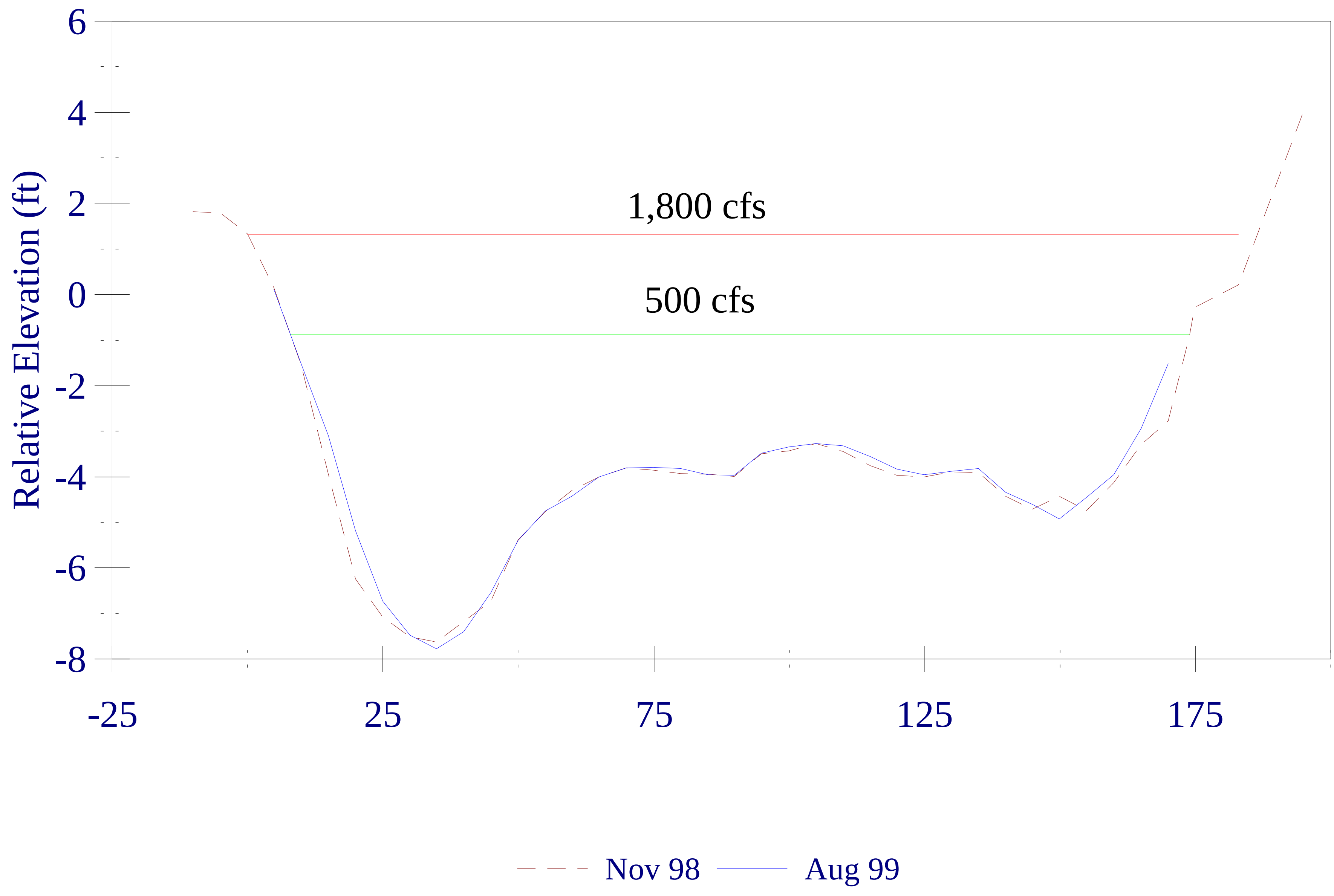

R14
1,800 cfs
500 cfs
Relative Elevation (ft)
2
1
0
-1
-2
-3
-4
-5
-20
0
20
40
60
80
100
120
140
160
180
200
Nov 98
Aug 99


R14A
1,800 cfs
500 cfs
Relative Elevation (ft)
2
1
0
-1
-2
-3
-4
-10
10
30
50
70
90
110
130
150
170
Nov 98
Aug 99

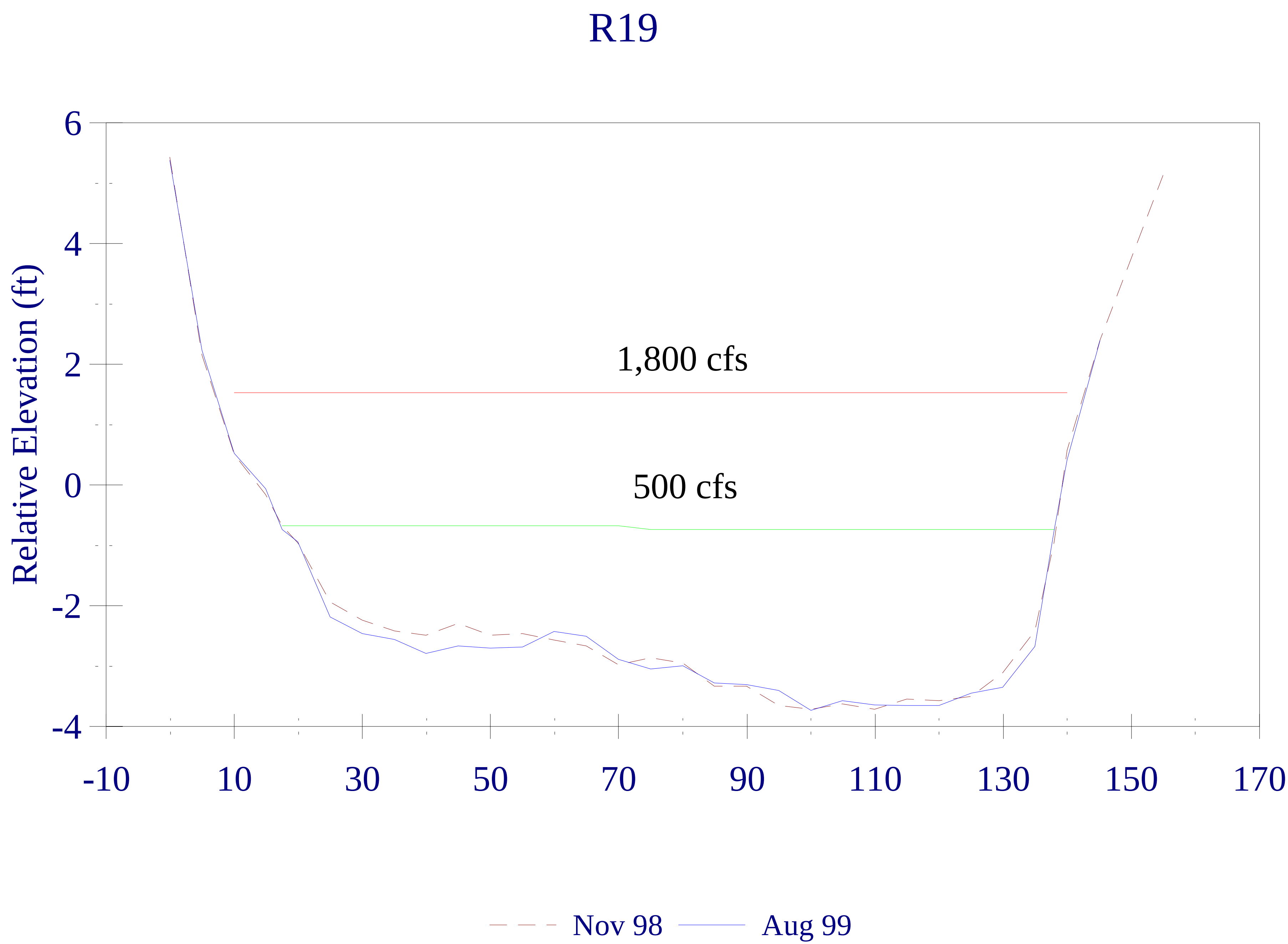


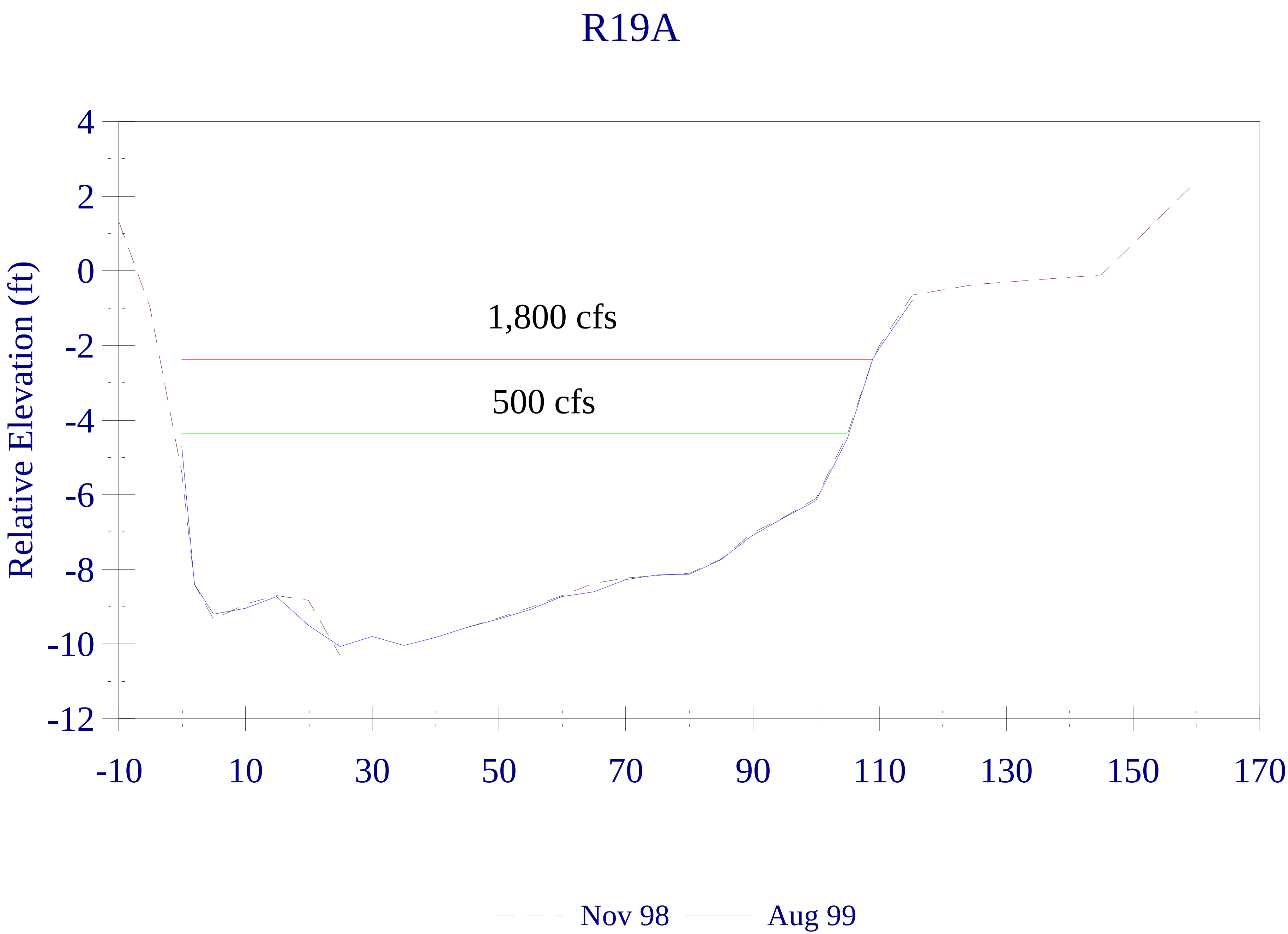
R15
1,800 cfs
500 cfs
Relative Elevation (ft)
4
2
0
-2
-4
-6
-8
-10
10
30
50
70
90
110
130
150
170
Nov 98
Aug 99

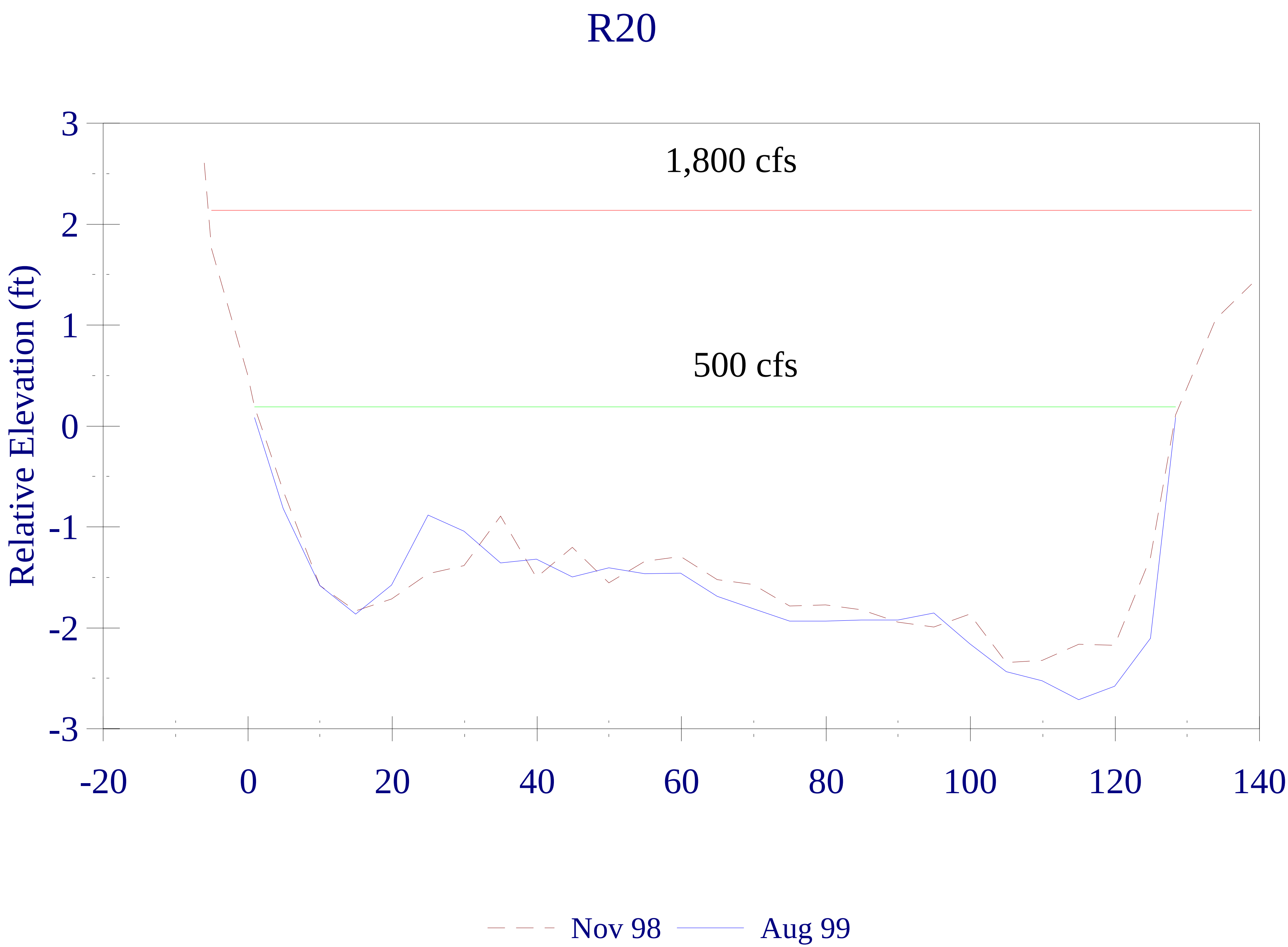
R16

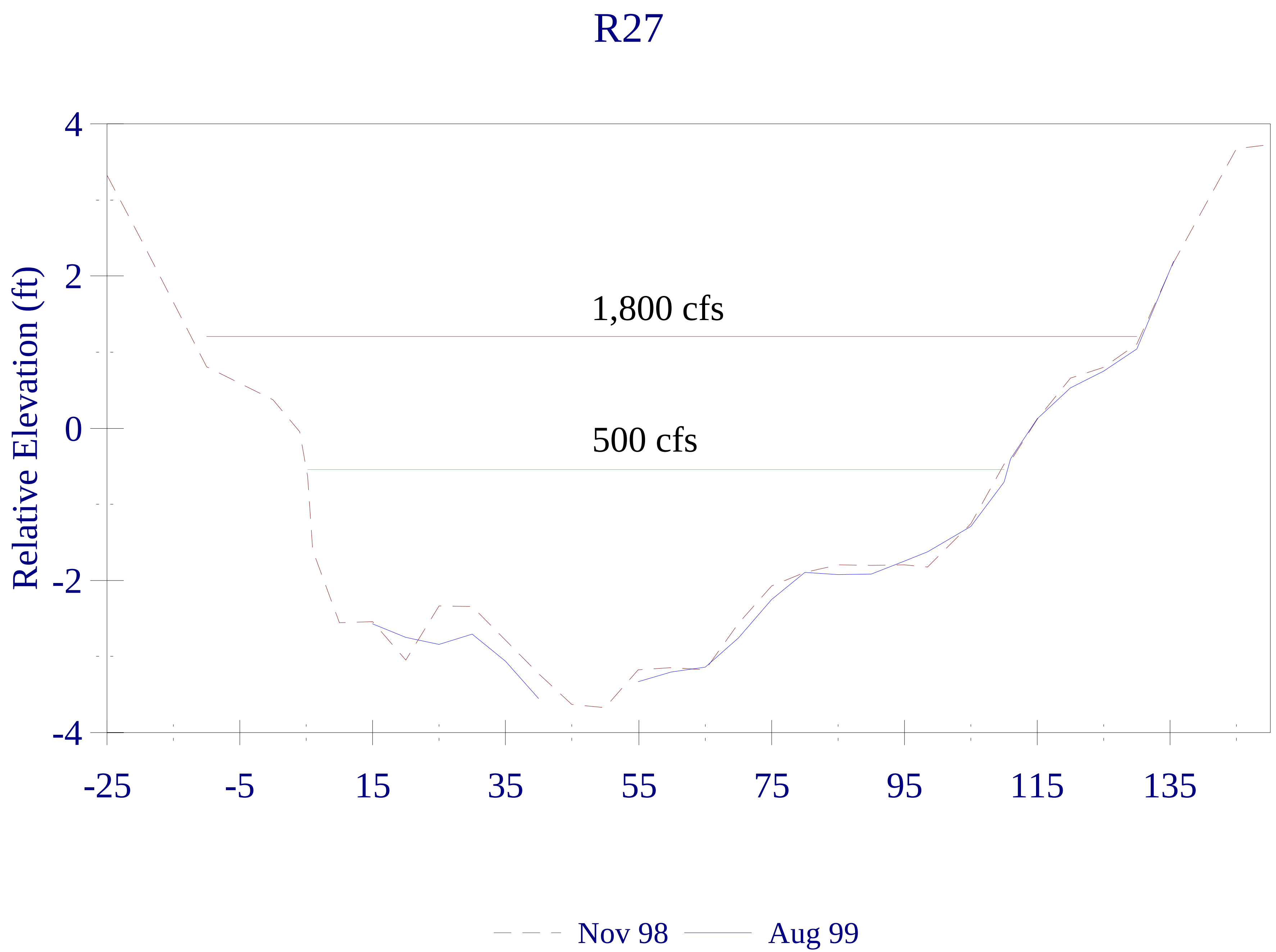


Relative Elevation (ft)
6
4
2
0
-2
-4
-6
-8
-25
25
75
125
175
1,800 cfs
500 cfs
Nov 98
Aug 99


R19
Relative Elevation (ft)
6
4
2
0
-2
-4
-10
10
30
50
70
90
110
130
150
170
1,800 cfs
500 cfs
Nov 98
Aug 99

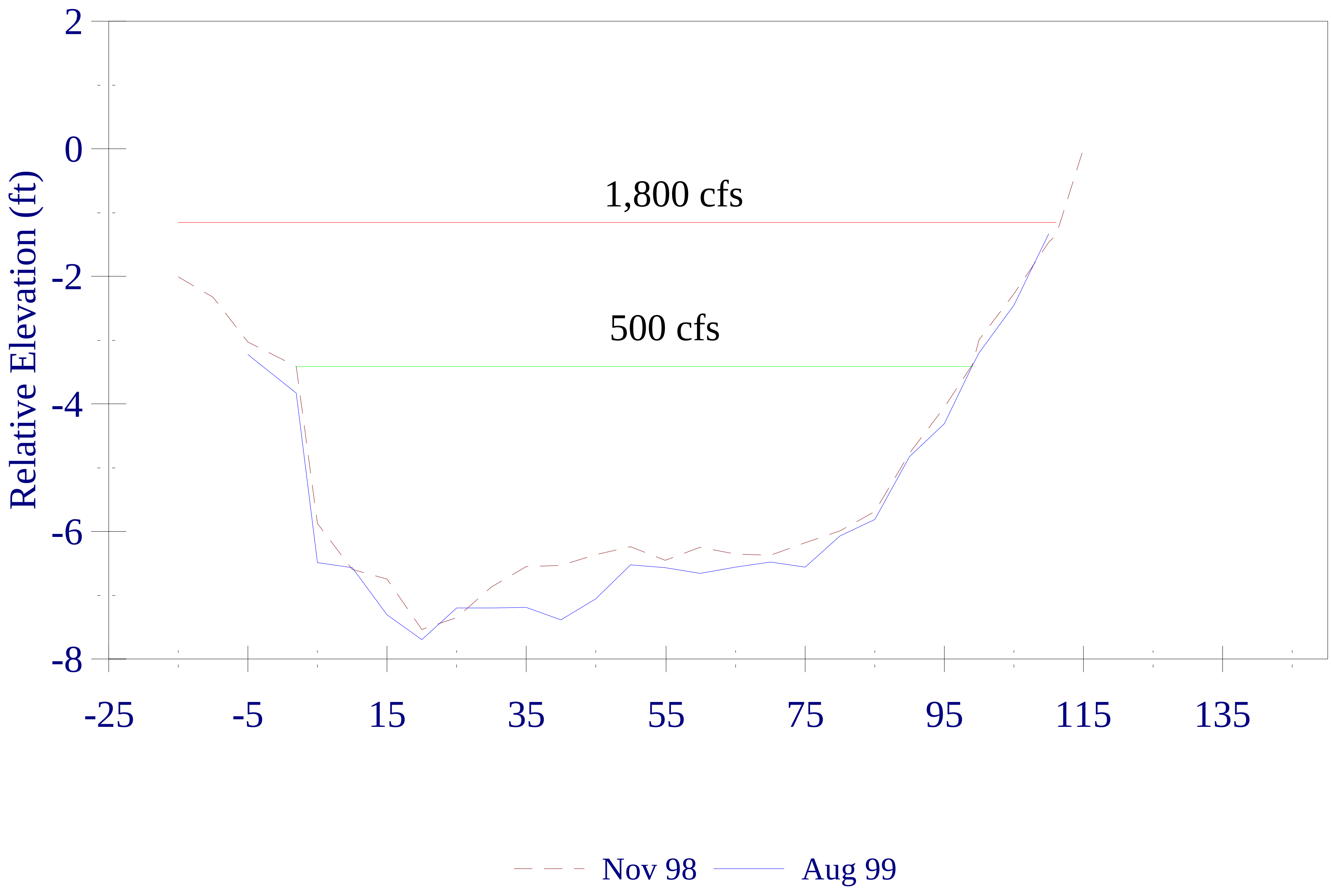

R19A
Relative Elevation (ft)
4
2
0
-2
-4
-6
-8
-10
-12
-10
10
30
50
70
90
110
130
150
170
1,800 cfs
500 cfs
Nov 98
Aug 99


R20
1,800 cfs
500 cfs
Relative Elevation (ft)
3
2
1
0
-1
-2
-3
-20
0
20
40
60
80
100
120
140
Nov 98
Aug 99

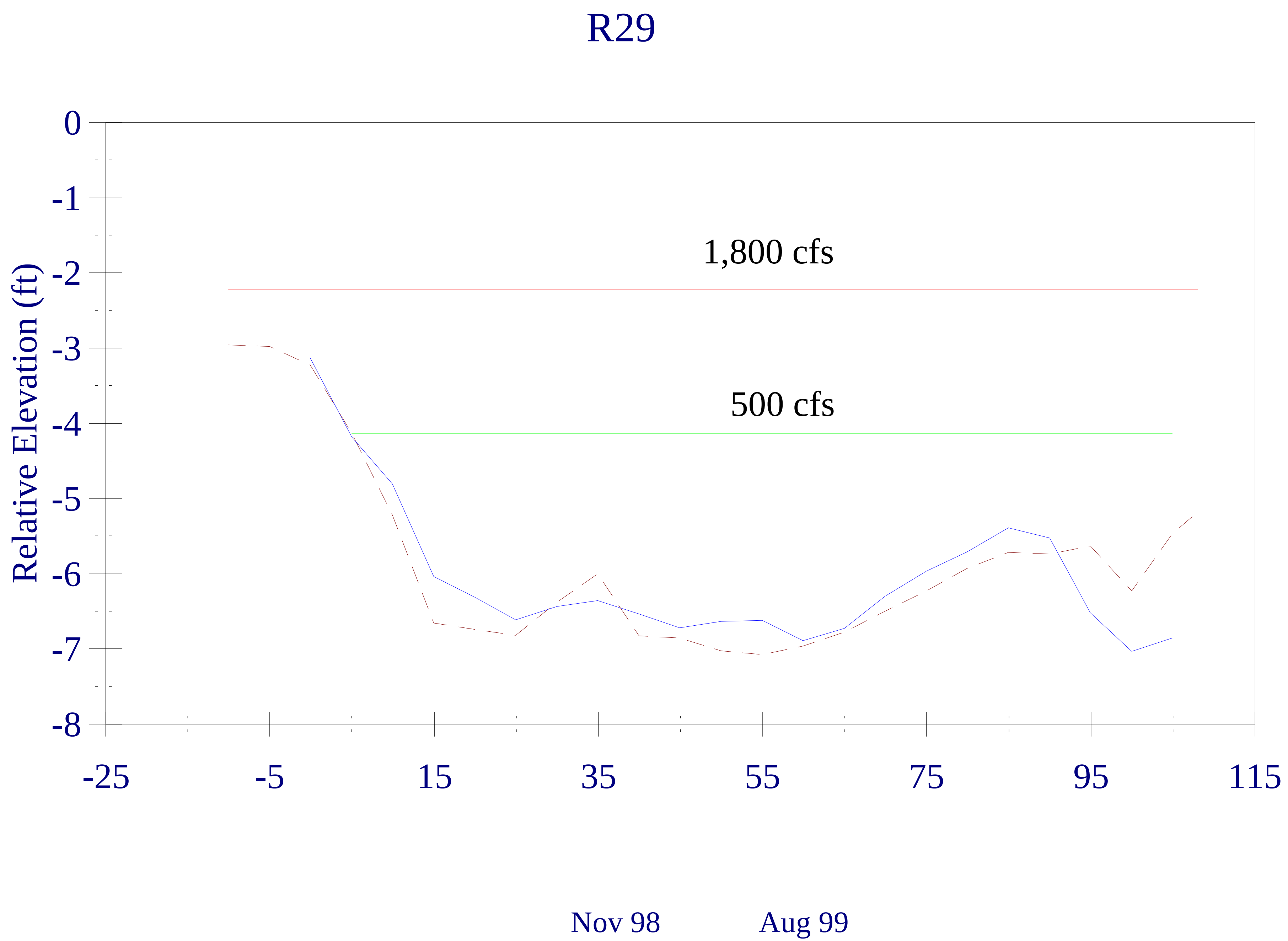


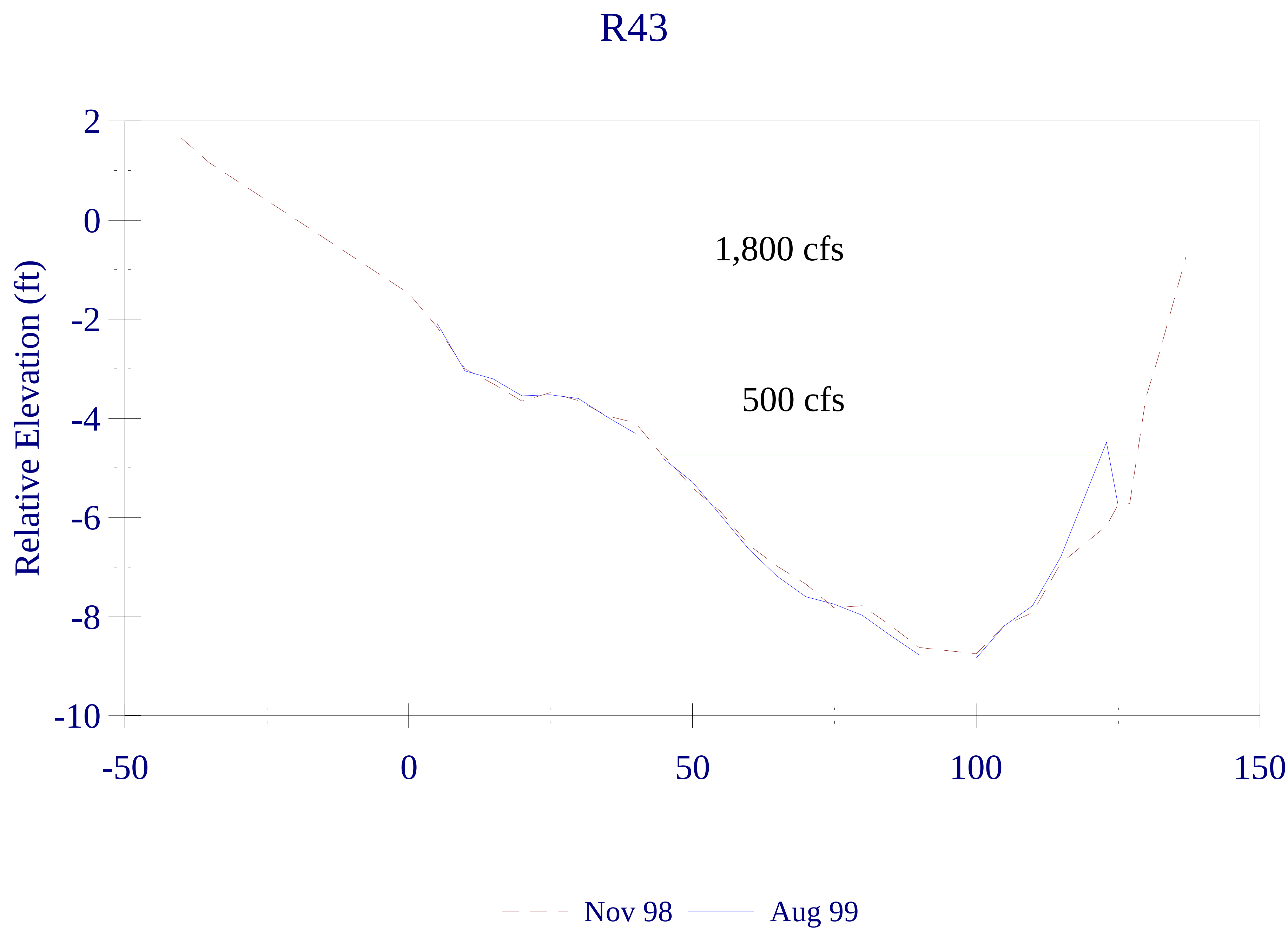
R27
Relative Elevation (ft)
4
2
0
-2
-4
1,800 cfs
500 cfs
-25
-5
15
35
55
75
95
115
135
Nov 98
Aug 99

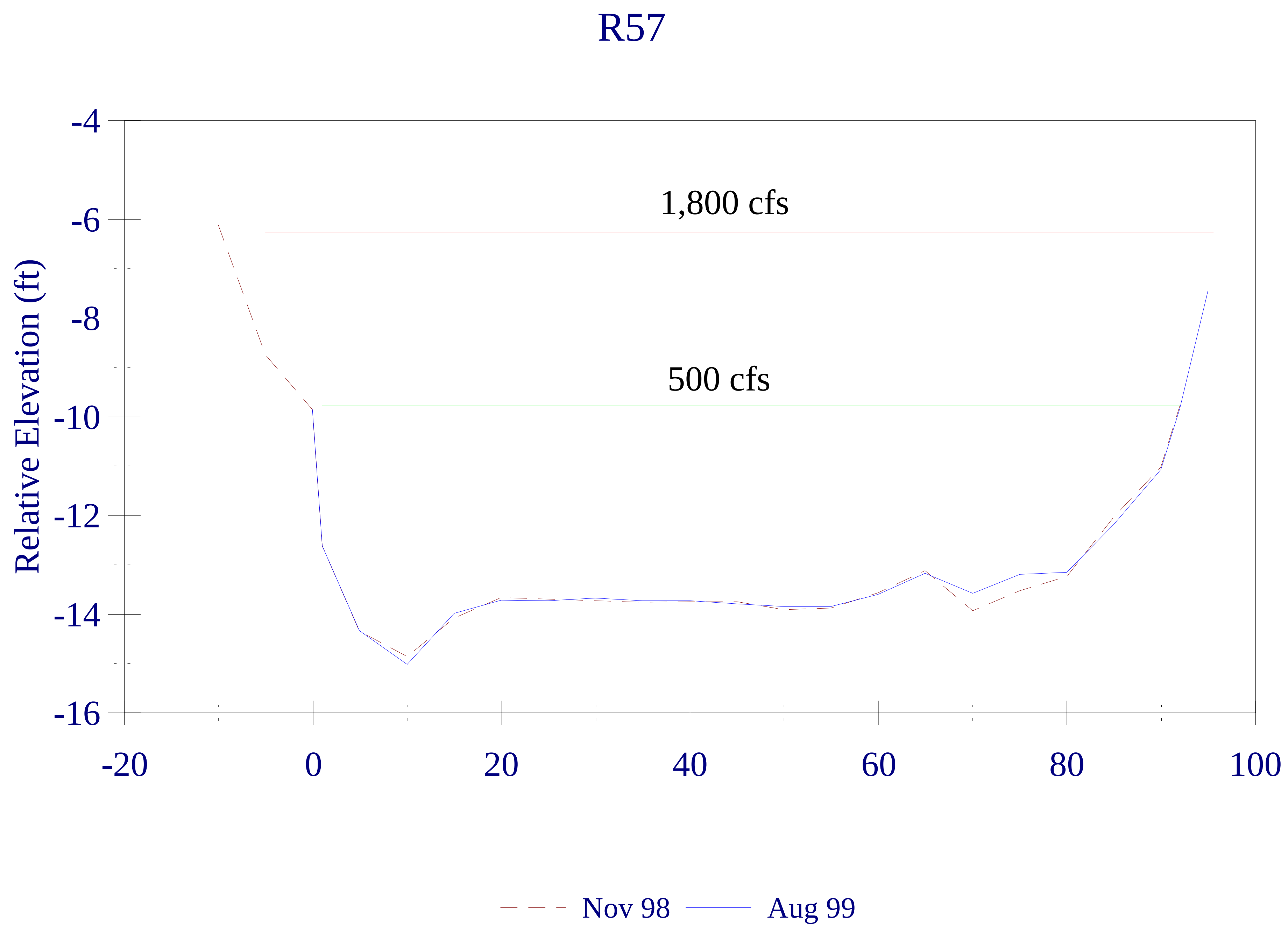
R28A

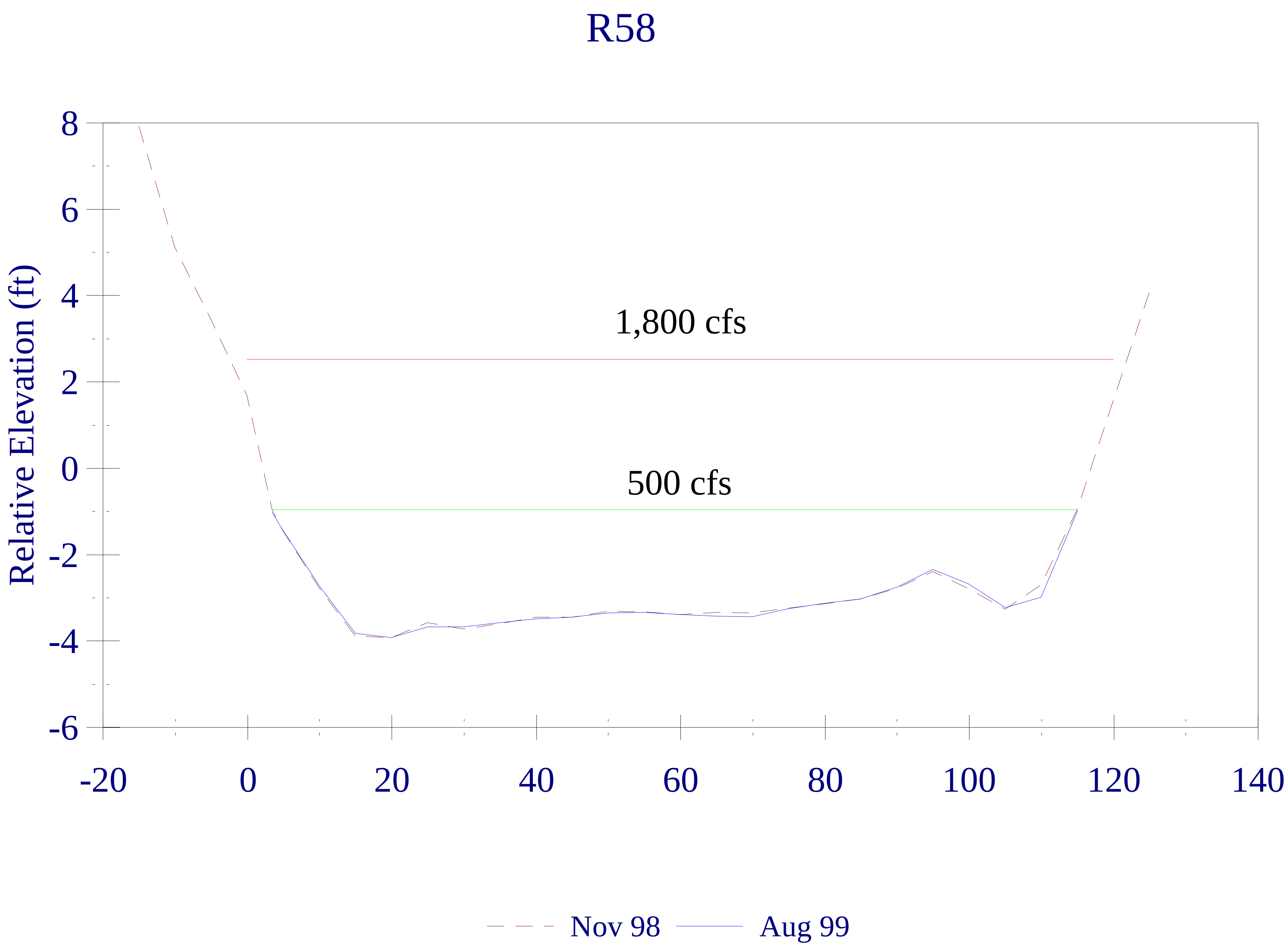


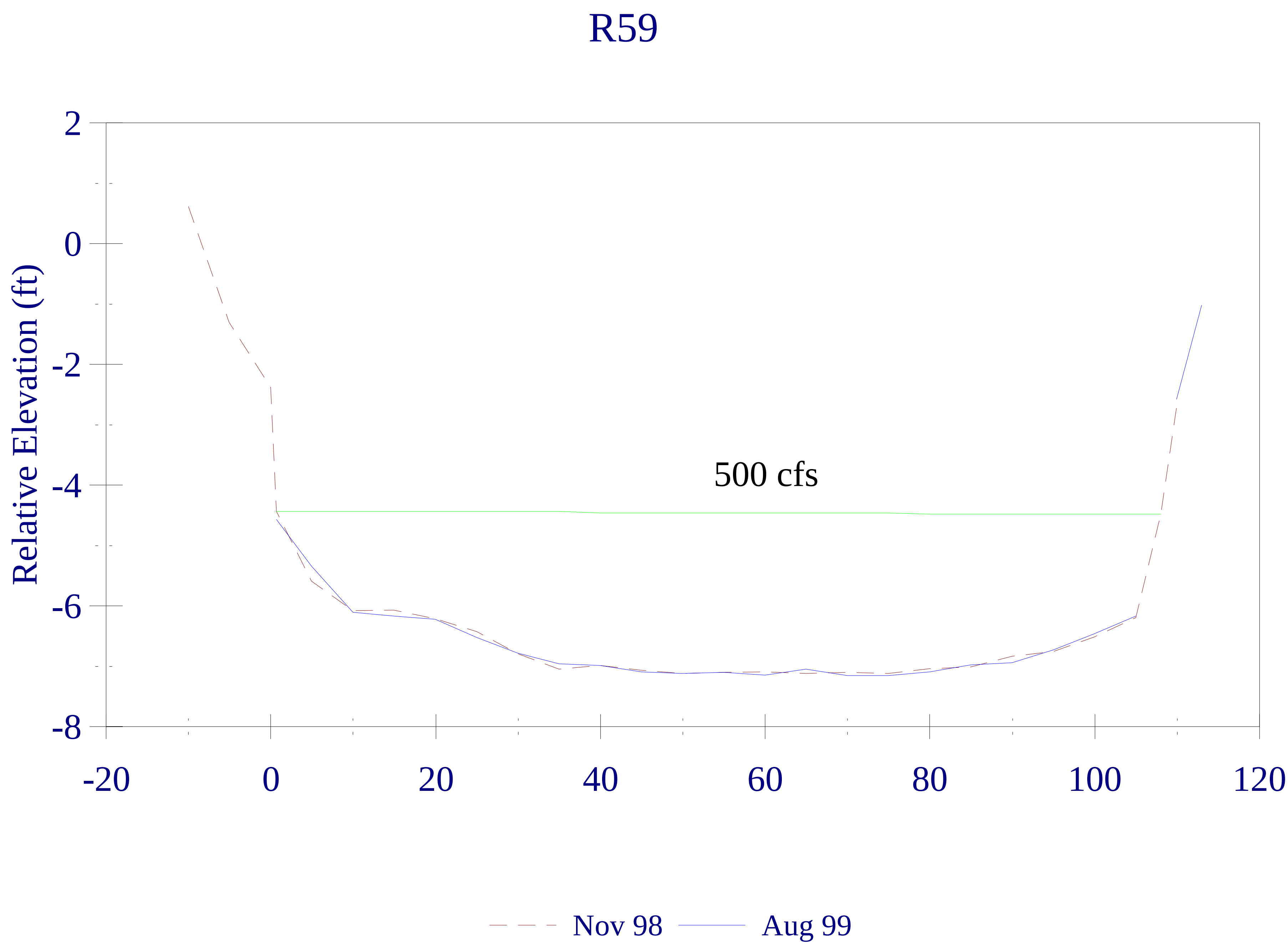
1,800 cfs
500 cfs
Relative Elevation (ft)
2
0
-2
-4
-6
-8
-25
-5
15
35
55
75
95
115
135
Nov 98
Aug 99

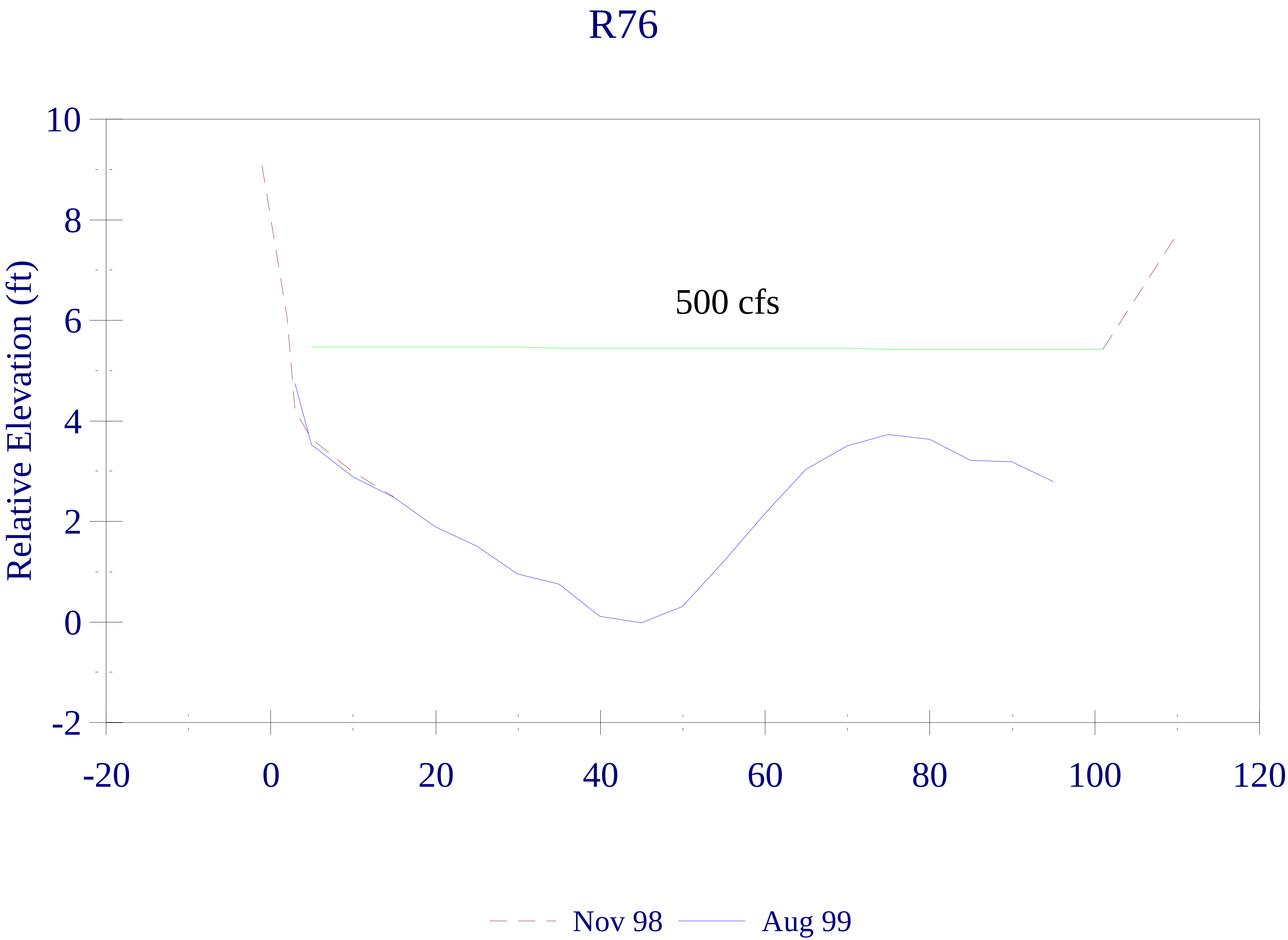

R29
1,800 cfs
500 cfs
Relative Elevation (ft)
0
-1
-2
-3
-4
-5
-6
-7
-8
-25
-5
15
35
55
75
95
115
Nov 98
Aug 99


R43
Relative Elevation (ft)
2
0
-2
-4
-6
-8
-10
-50
0
50
100
150
1,800 cfs
500 cfs
Nov 98
Aug 99

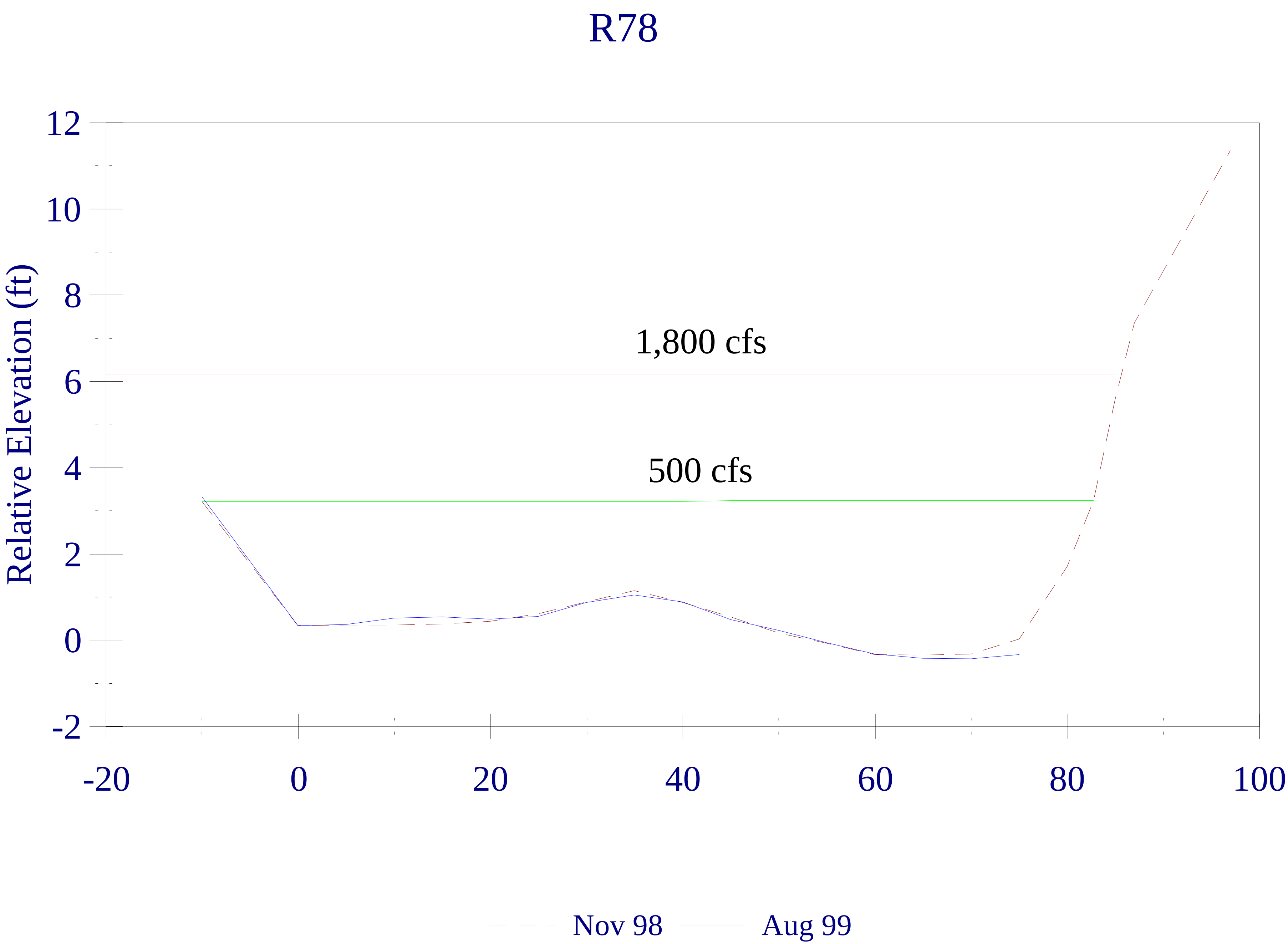

R57
1,800 cfs
500 cfs
Relative Elevation (ft)
-4
-6
-8
-10
-12
-14
-16
-20
0
20
40
60
80
100
Nov 98
Aug 99


R58
Relative Elevation (ft)
8
6
4
2
0
-2
-4
-6
-20
0
20
40
60
80
100
120
140
1,800 cfs
500 cfs
Nov 98
Aug 99


R59
Relative Elevation (ft)
2
0
-2
-4
-6
-8
-20
0
20
40
60
80
100
120
500 cfs
Nov 98
Aug 99

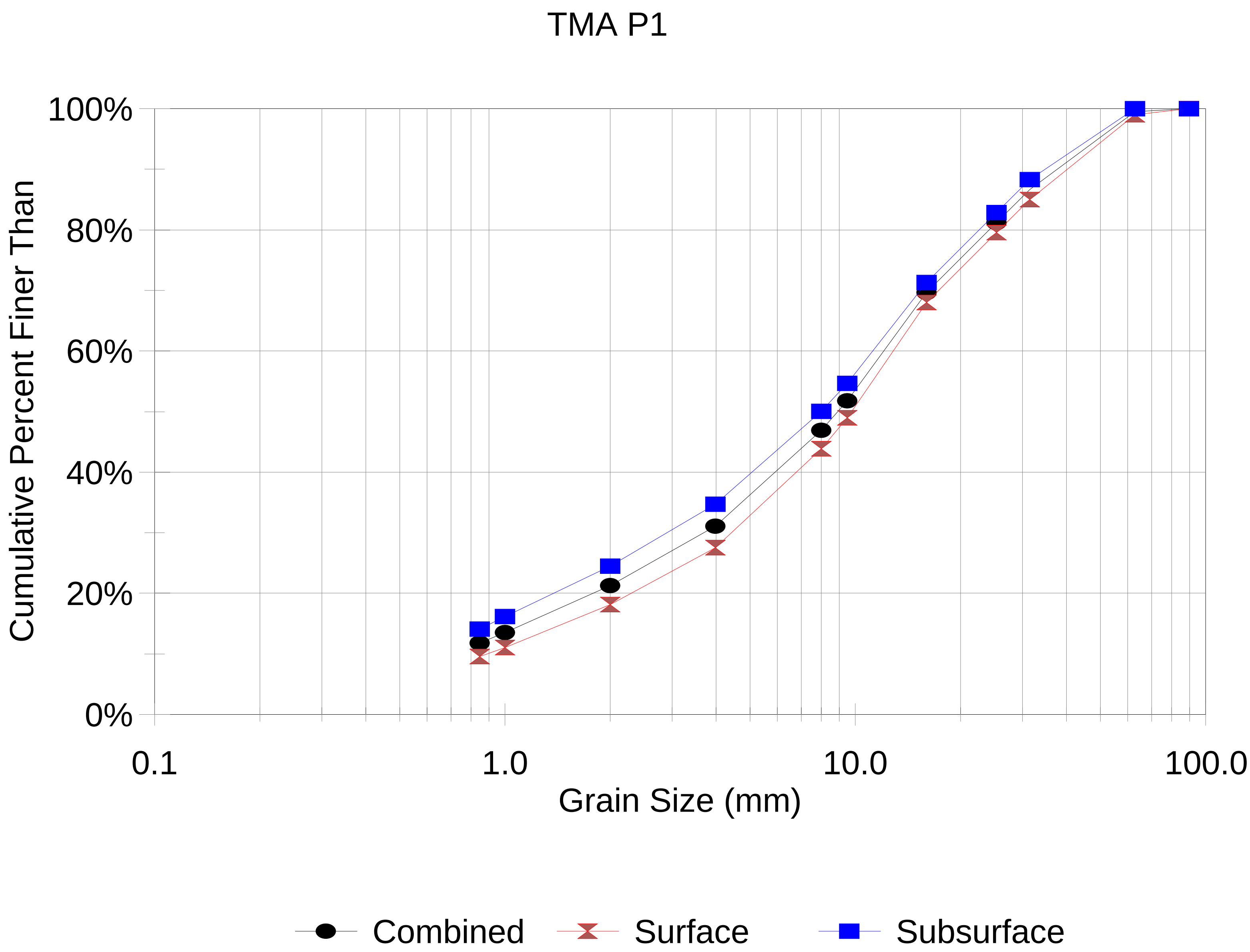


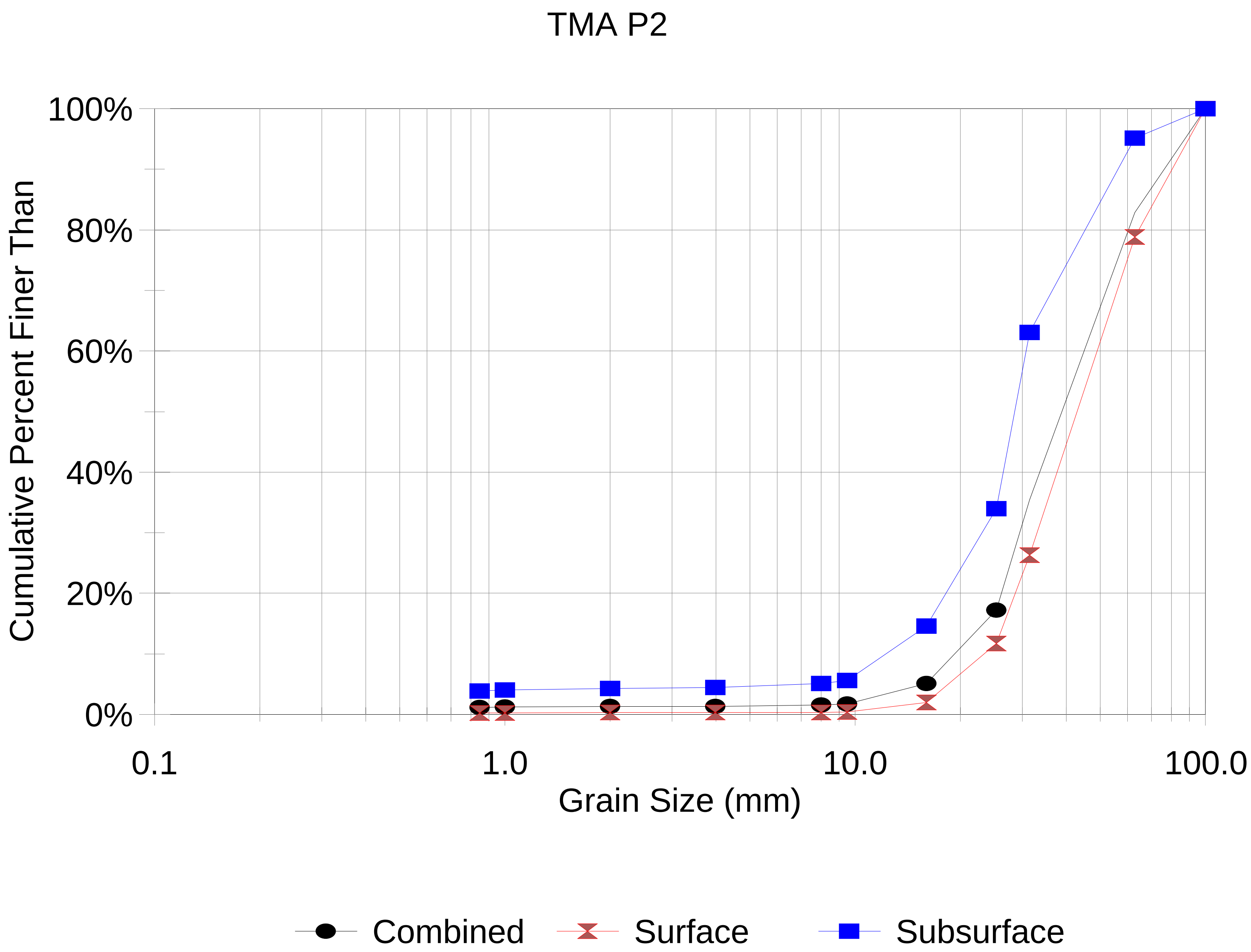
R76
Relative Elevation (ft)
10
8
6
4
2
0
-2
-20
0
20
40
60
80
100
120
500 cfs
Nov 98
Aug 99

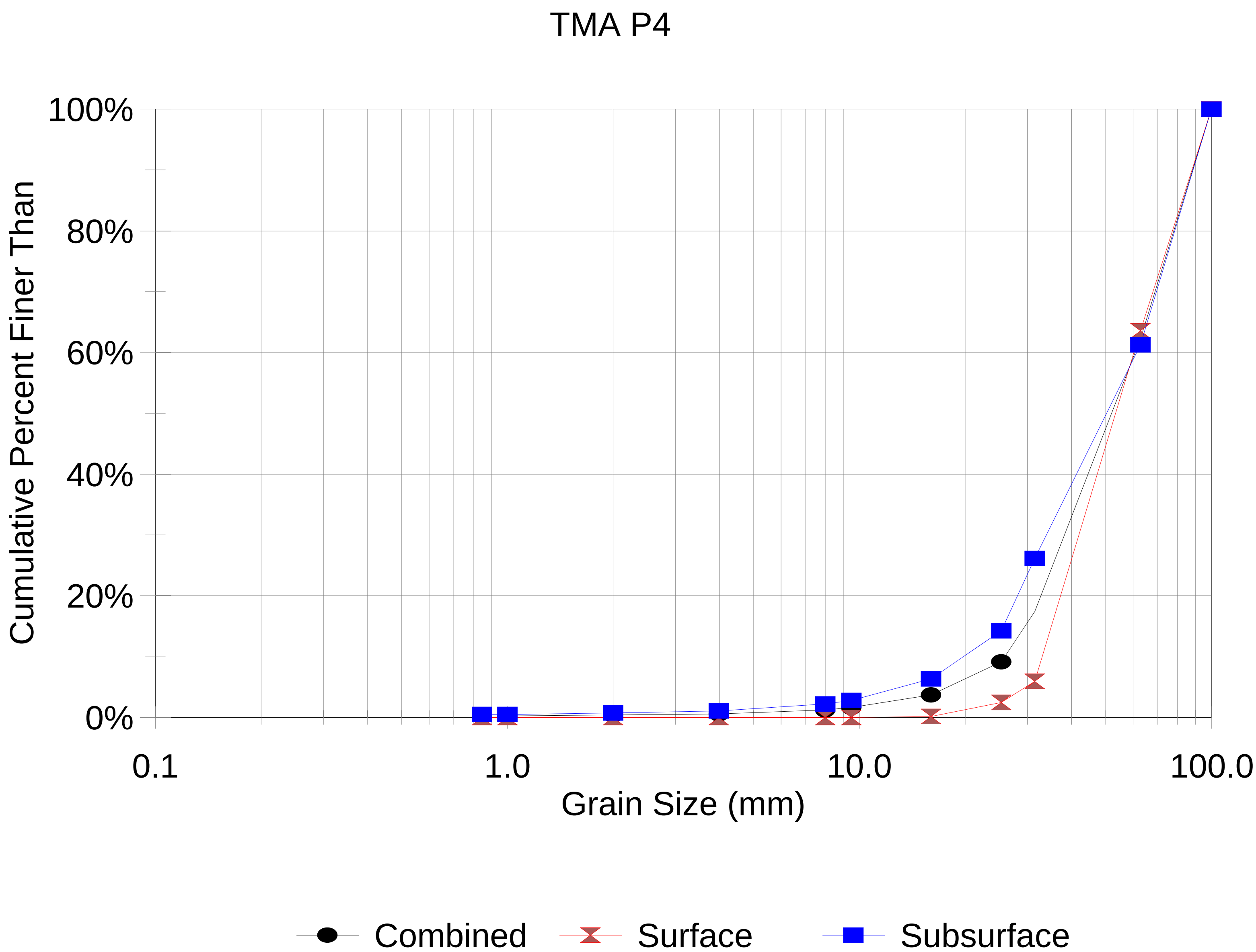

R78
1,800 cfs
500 cfs
Relative Elevation (ft)
12
10
8
6
4
2
0
-2
-20
0
20
40
60
80
100
Nov 98
Aug 99

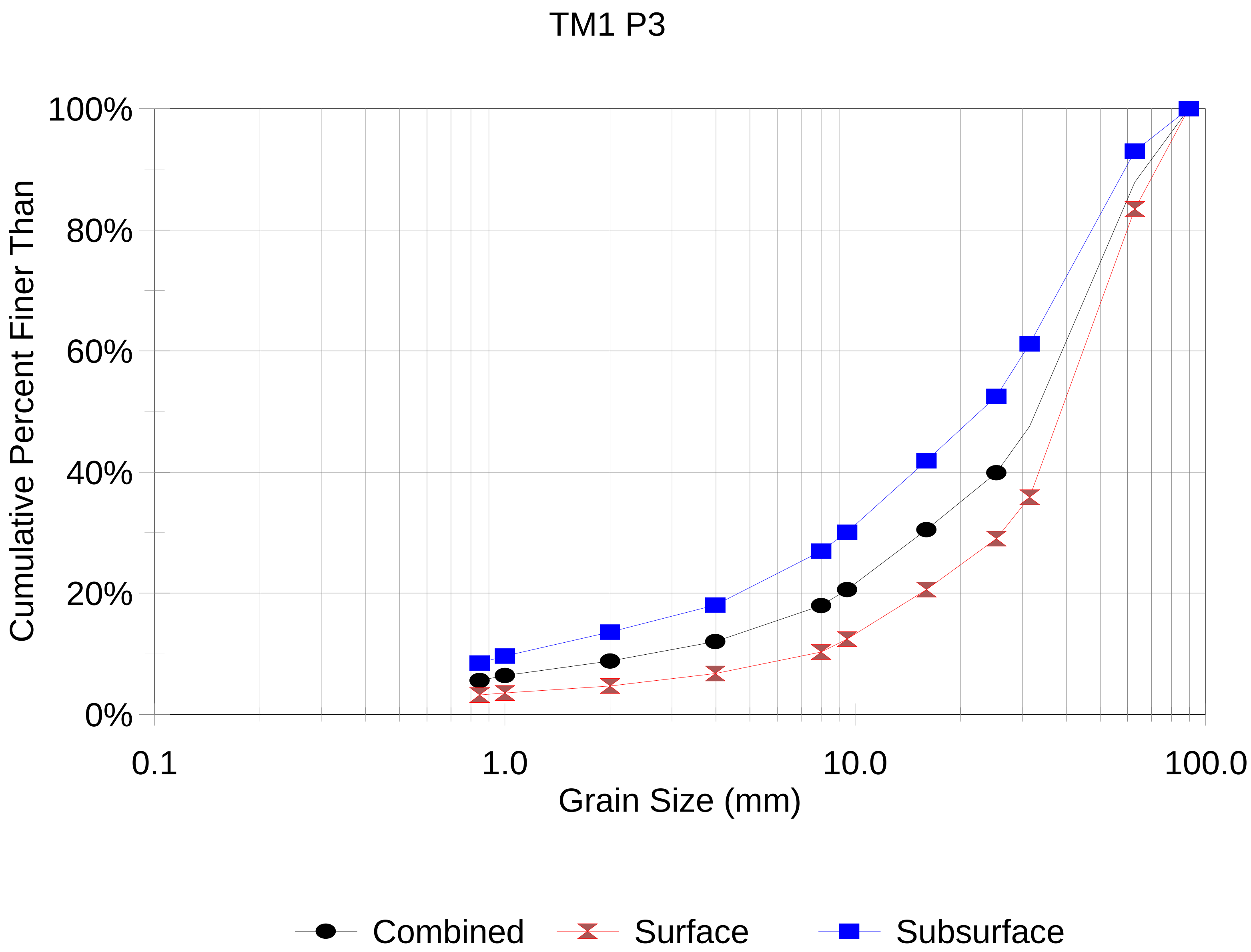
APPENDIX 5

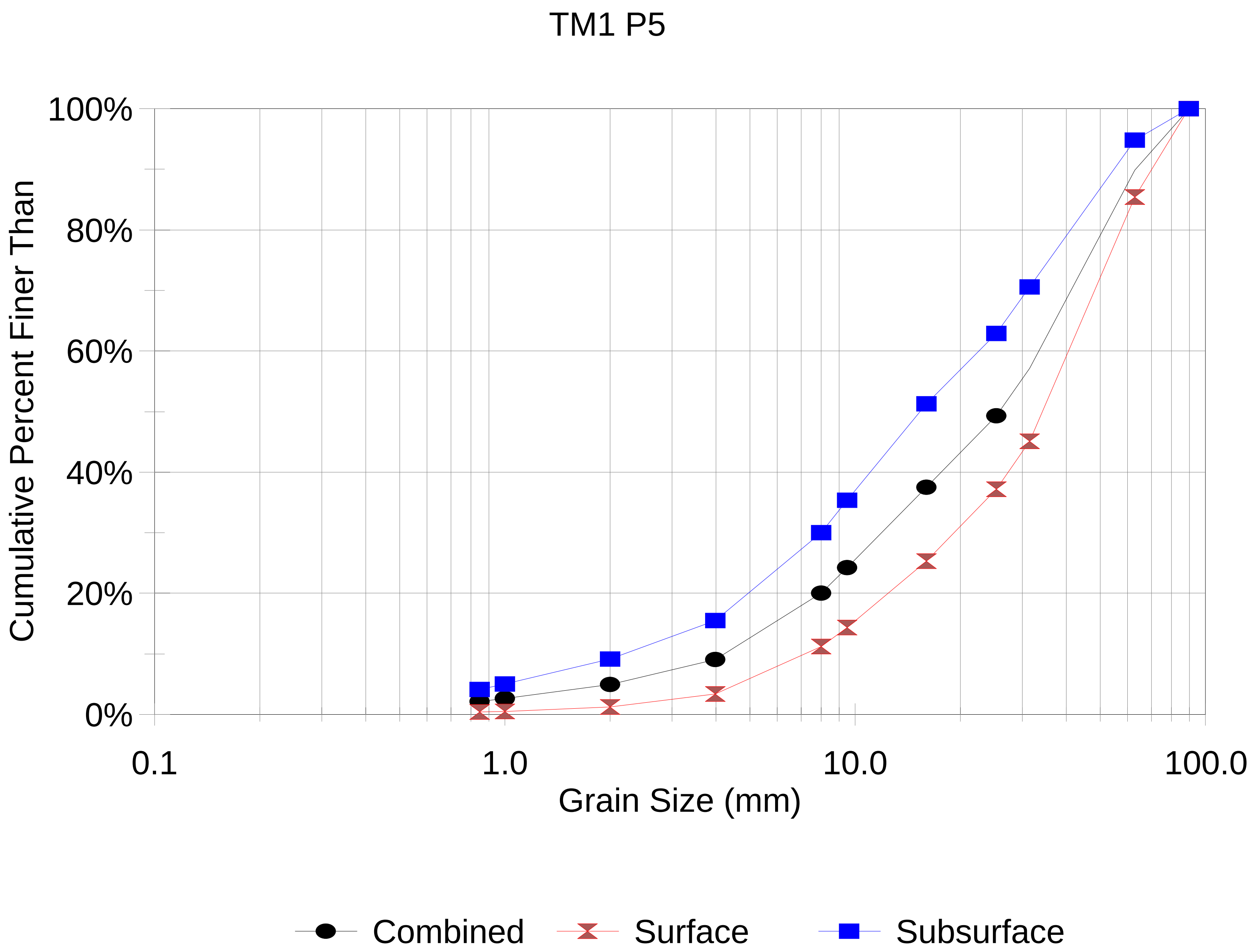
Cumulative Size Distribution Curves for Substrate Bulk Samples Taken at 25 Study Riffles in August 1999

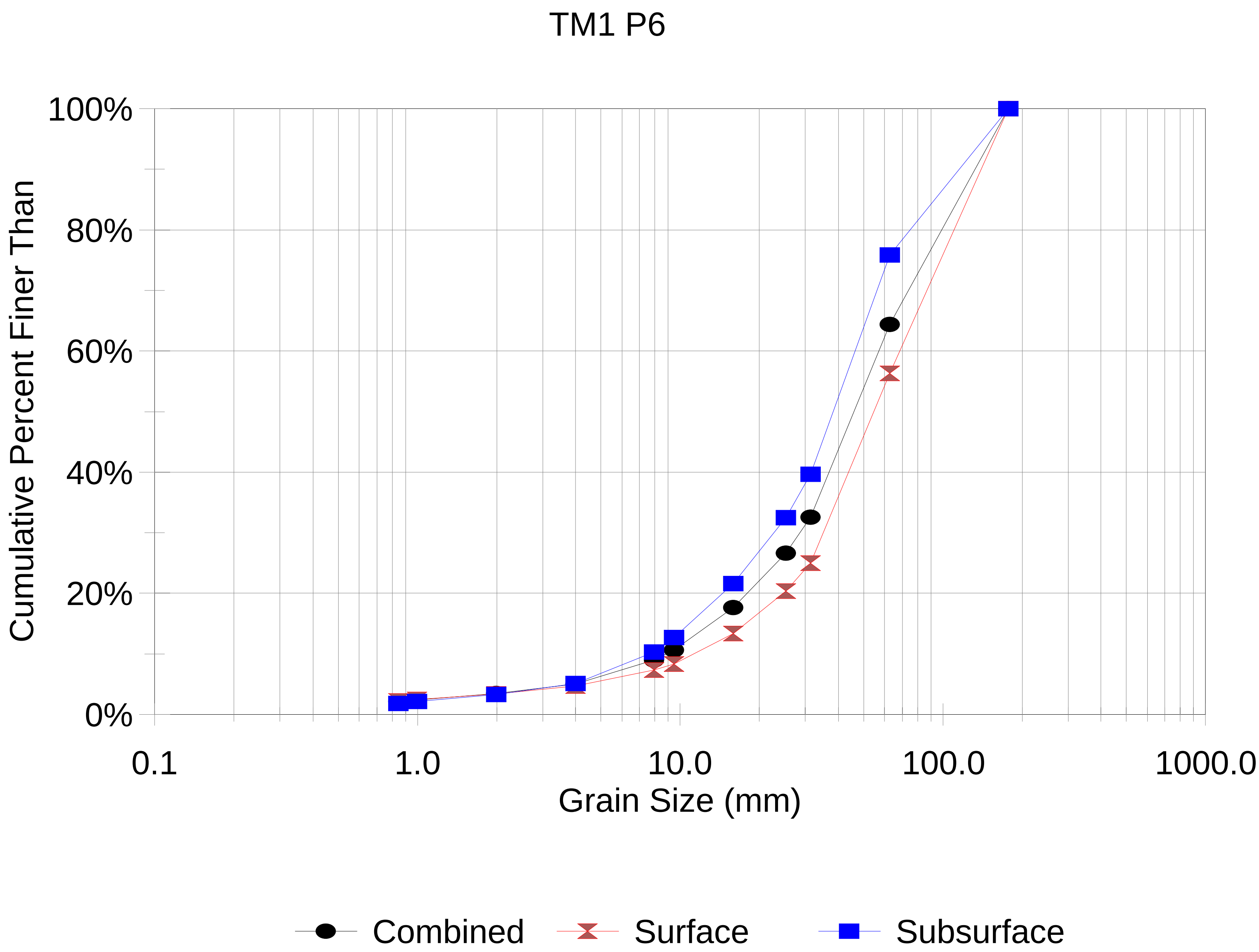

TMA P1
100%
80%
60%
40%
20%
0%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

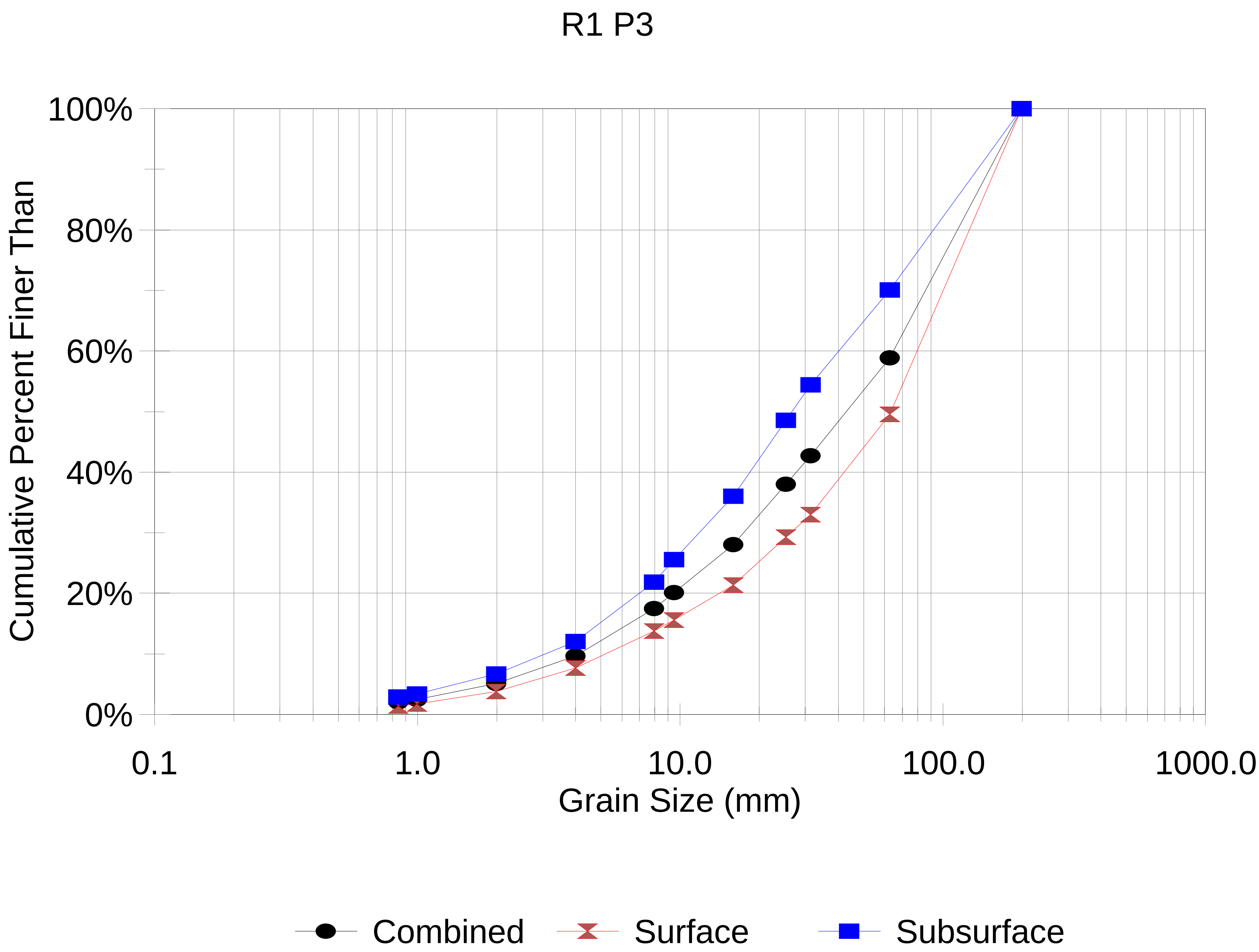

TMA P2
100%
80%
60%
40%
20%
0%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


TMA P4
100%
80%
60%
40%
20%
0%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

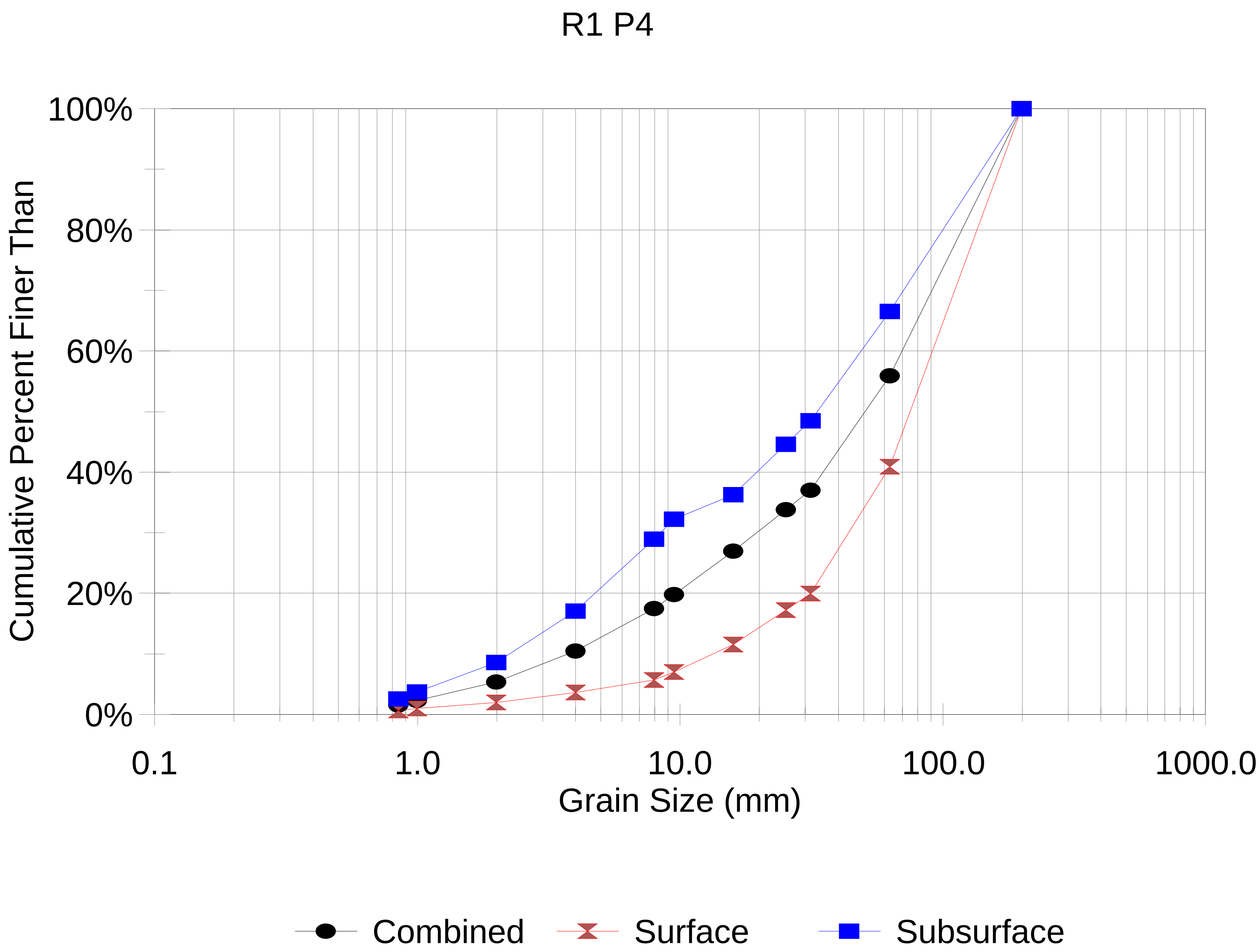

TM1 P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

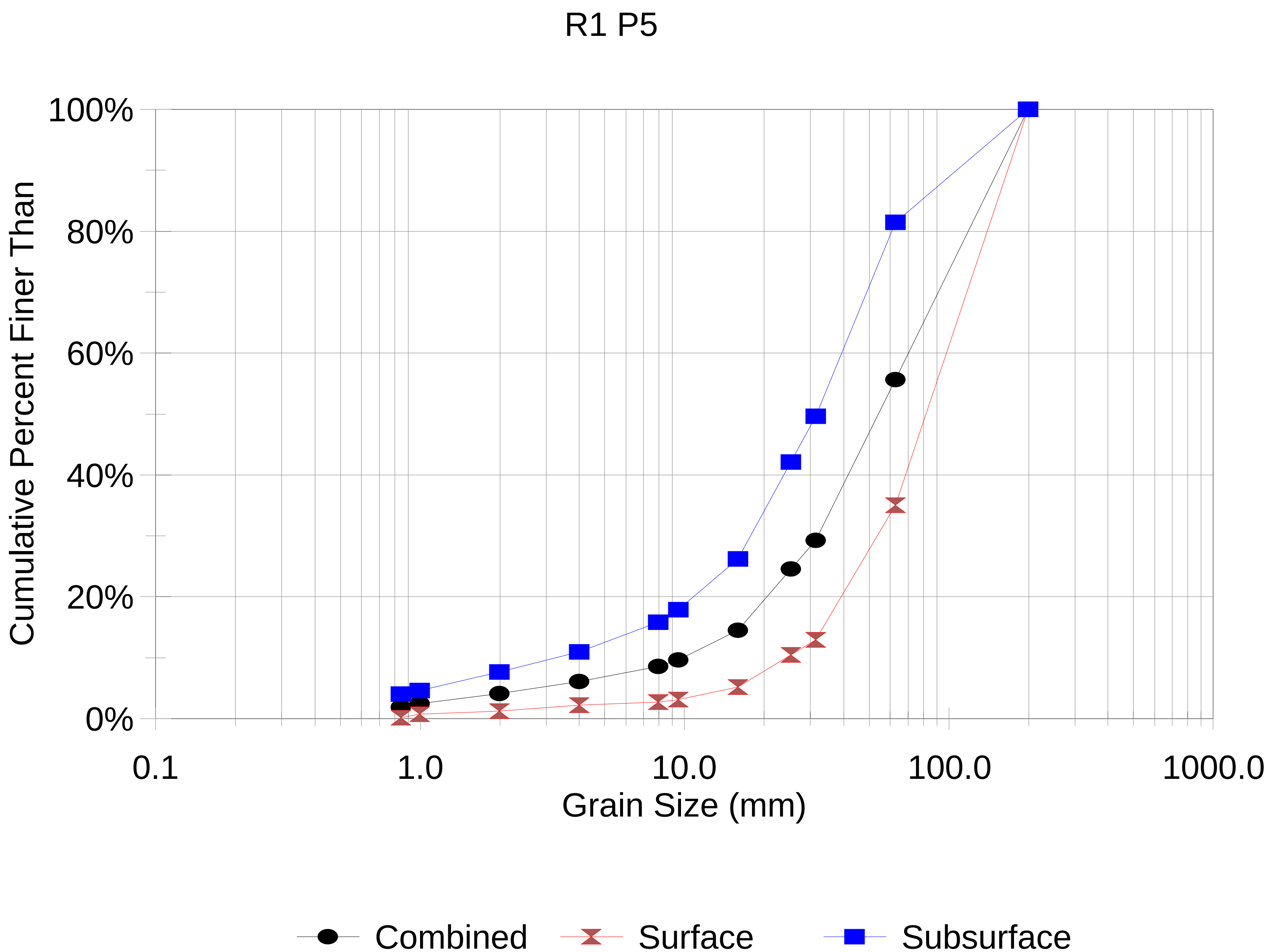

TM1 P5
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

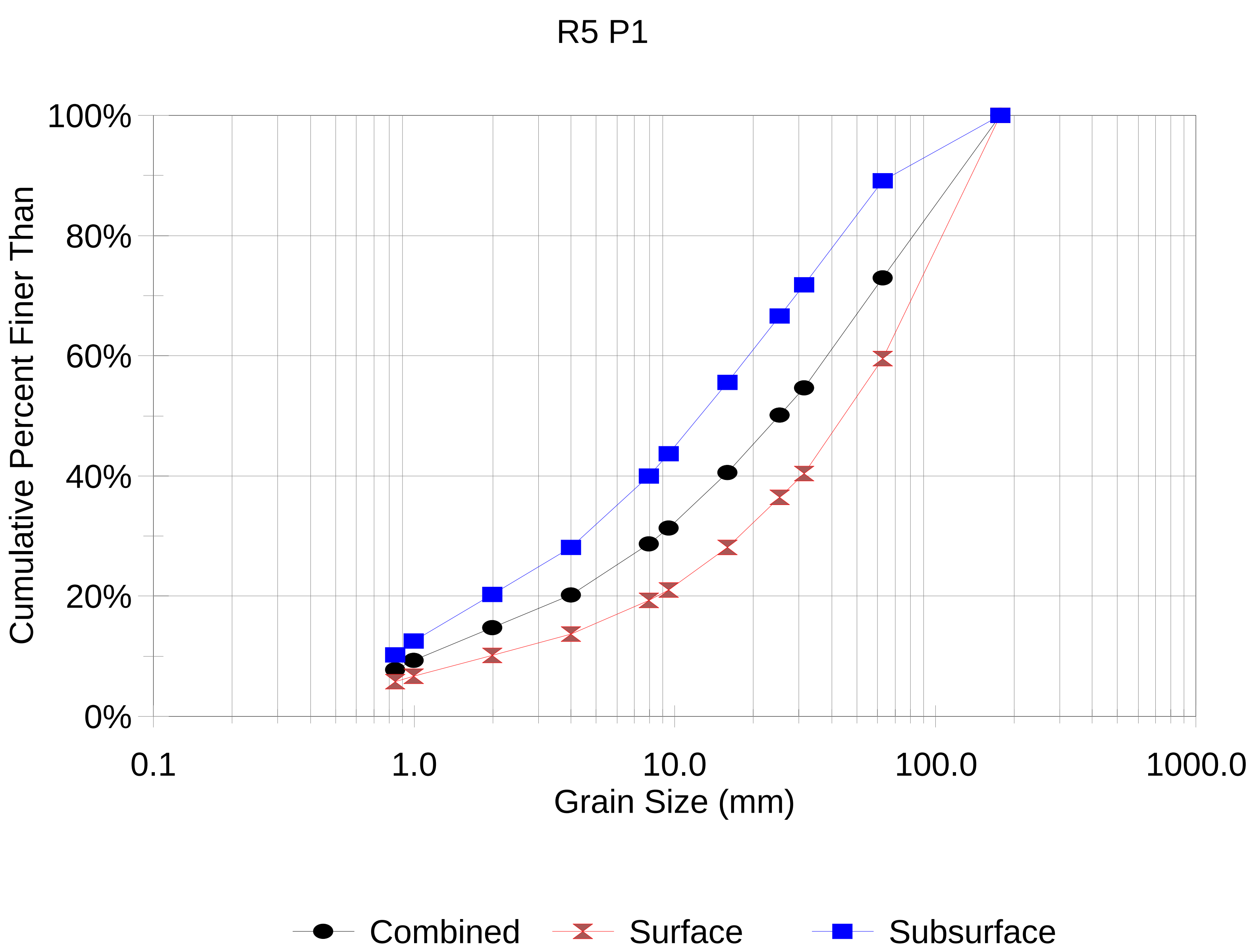

TM1 P6
100%
80%
60%
40%
20%
0%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface



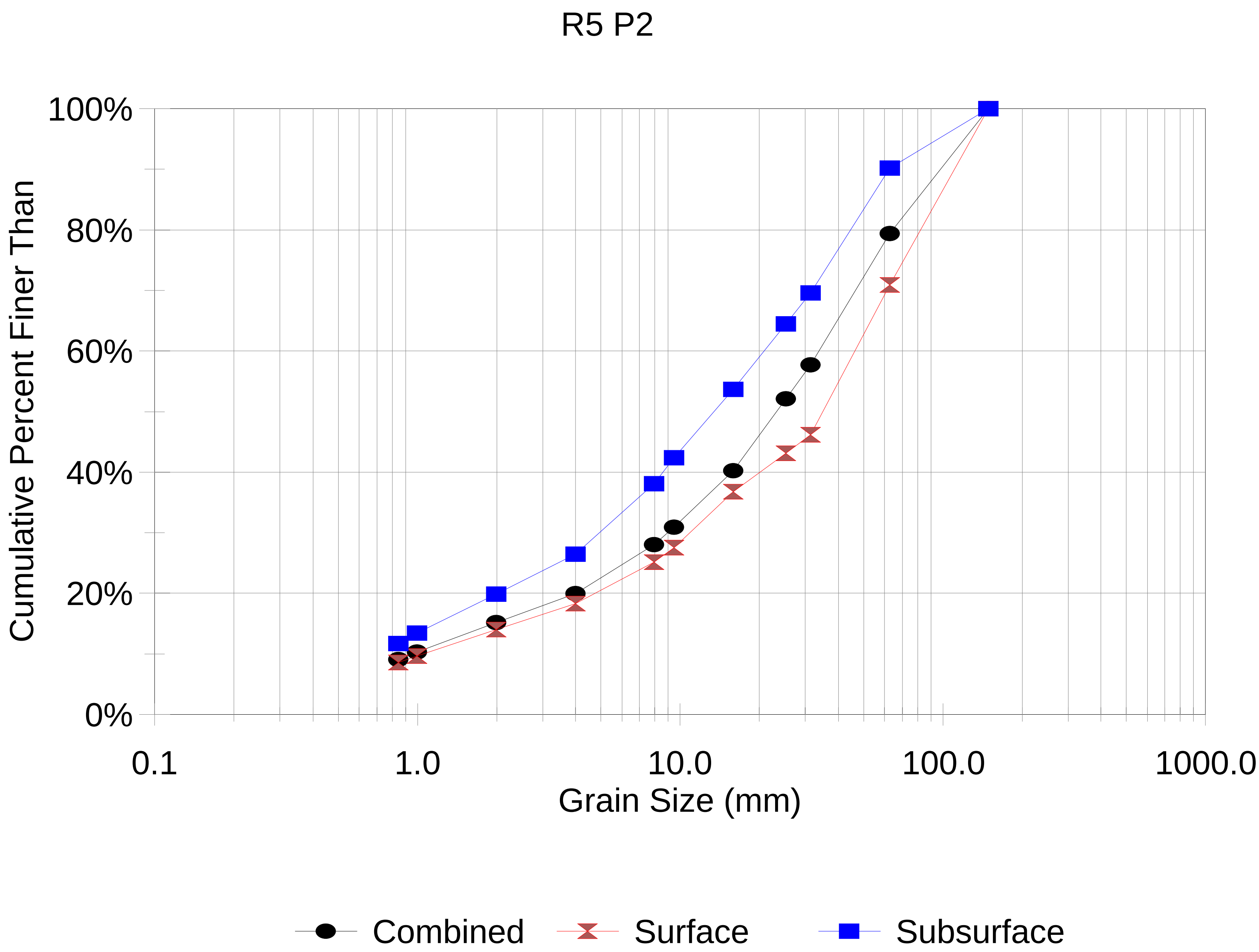
R1 P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface


R1 P4
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface

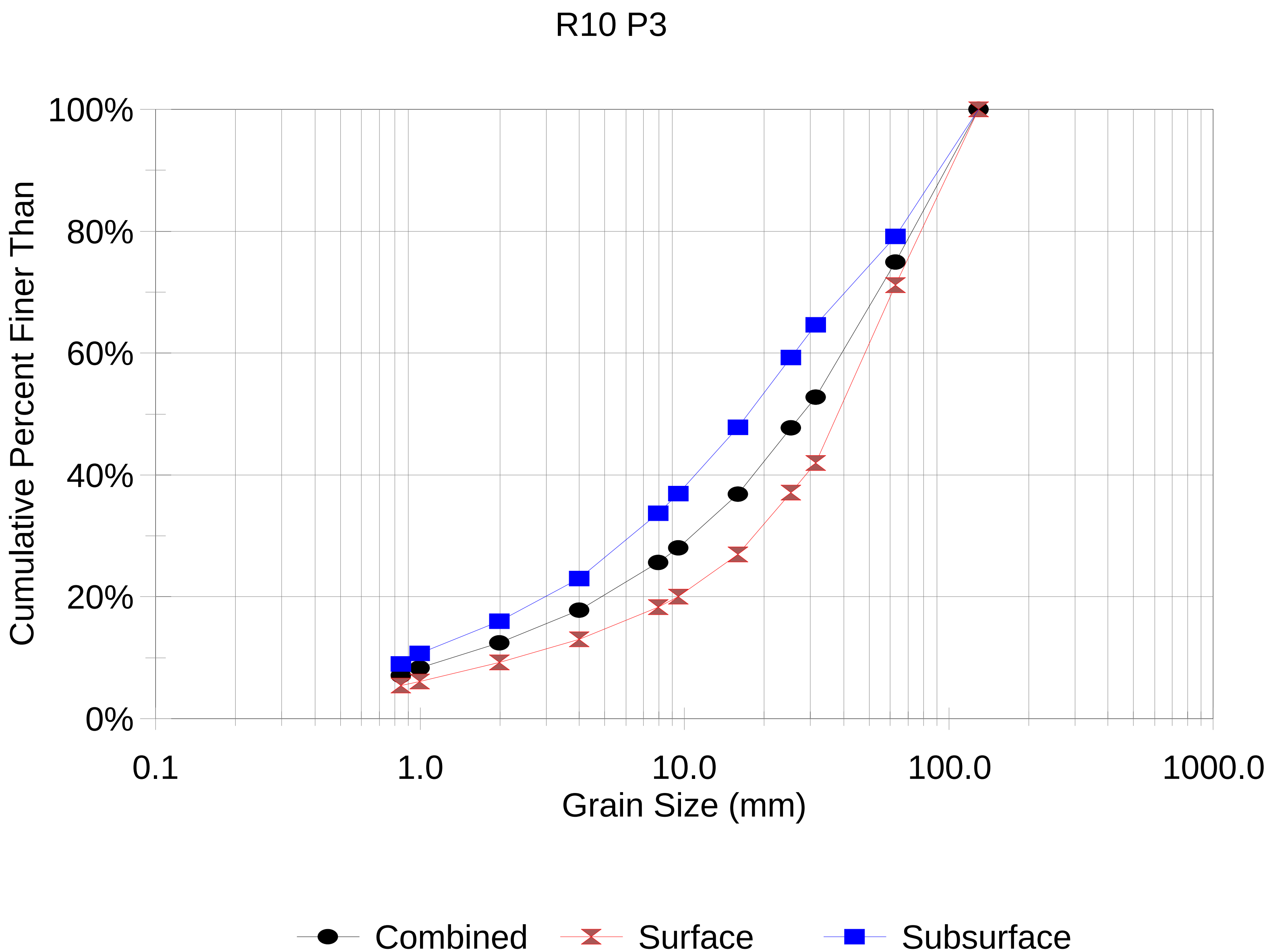

R1 P5
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface



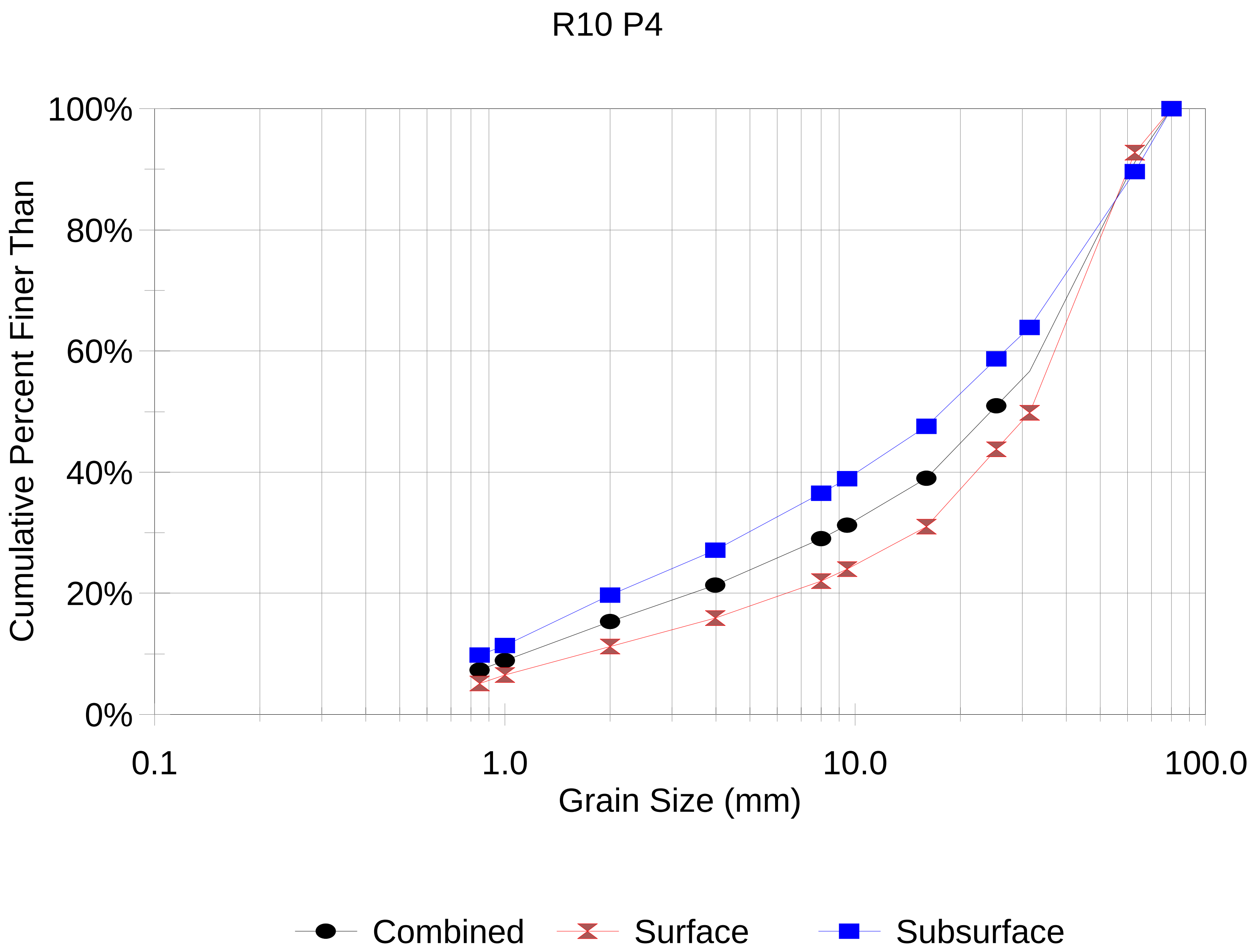
R5 P1
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface

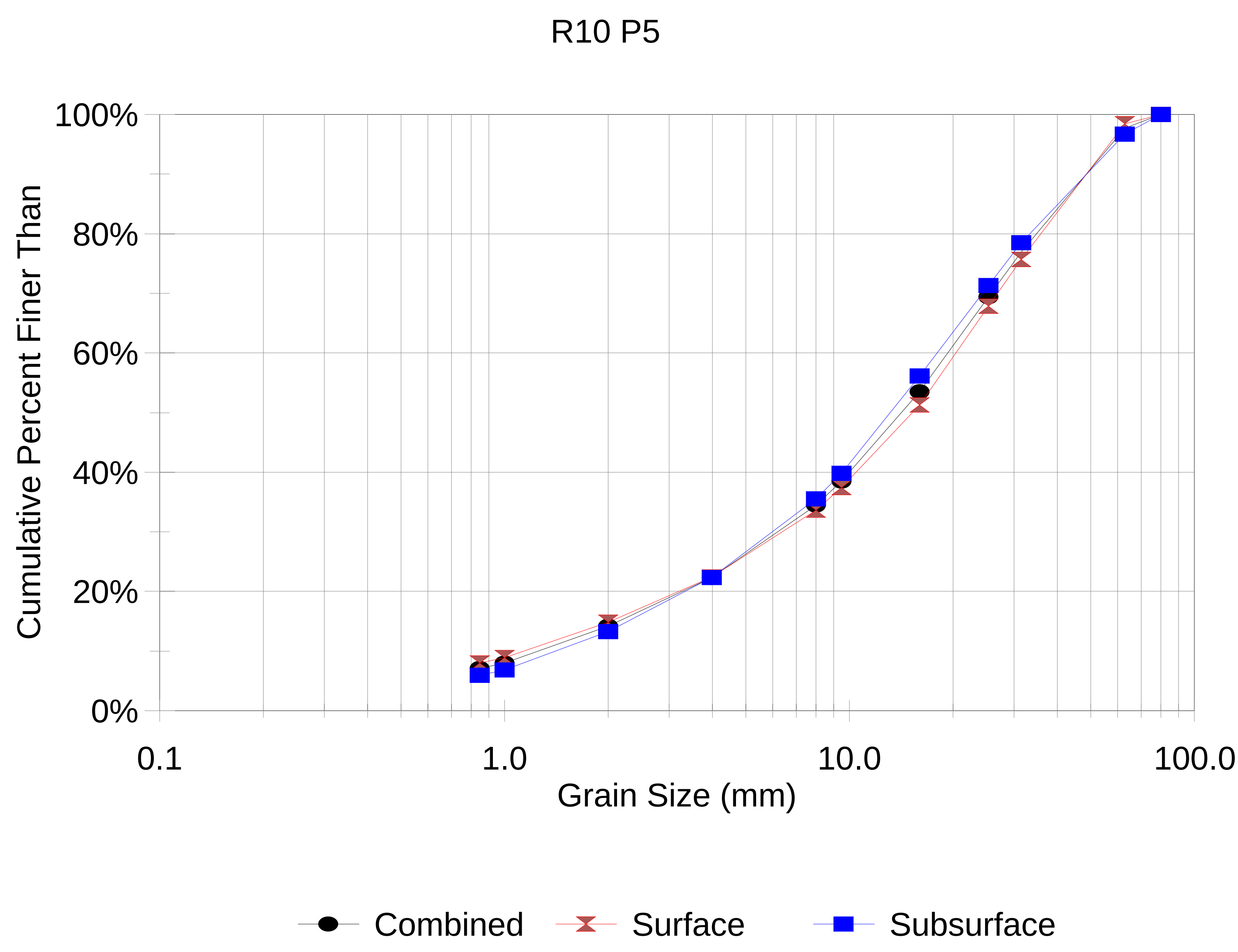


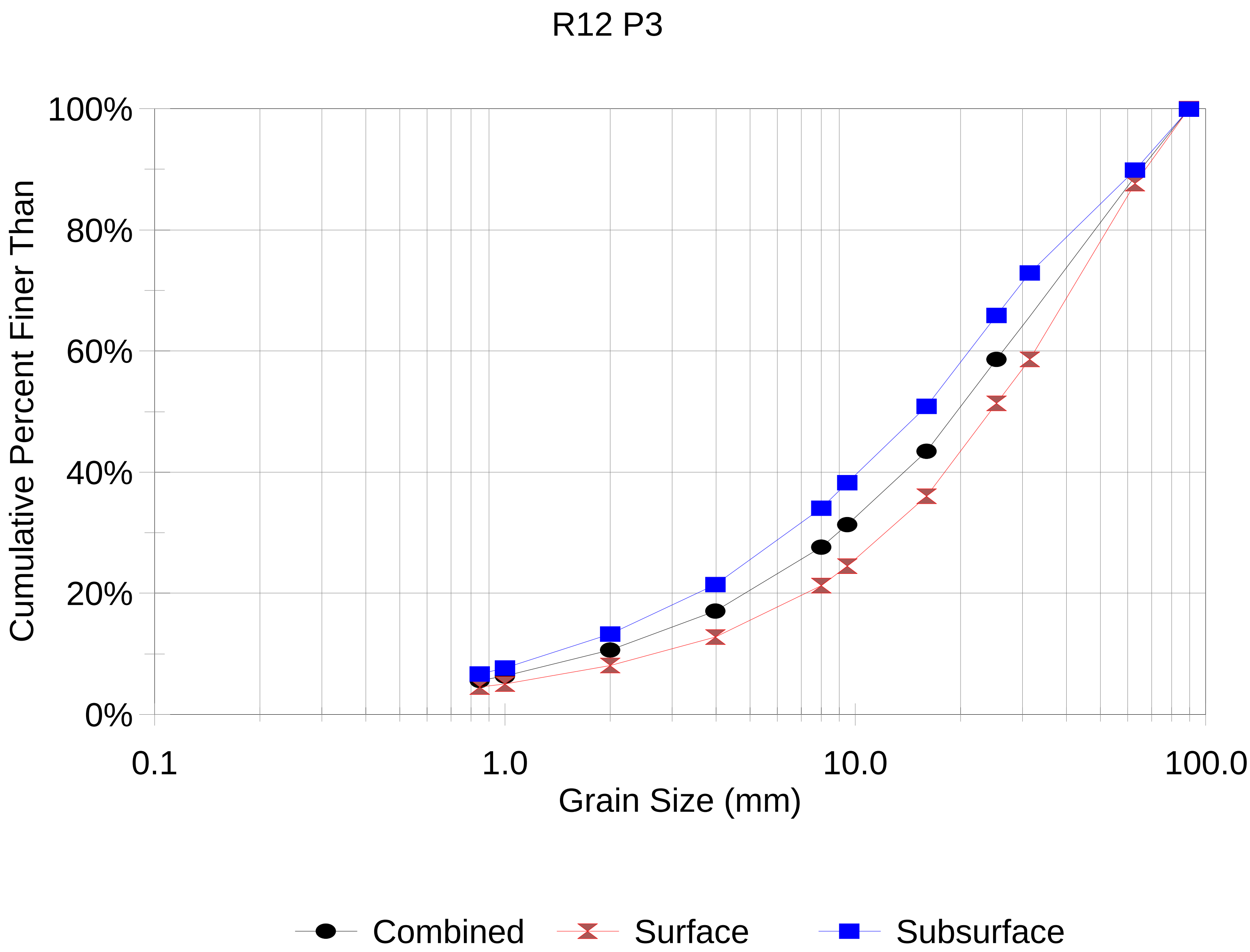
R5 P2
100%
80%
60%
40%
20%
0%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface



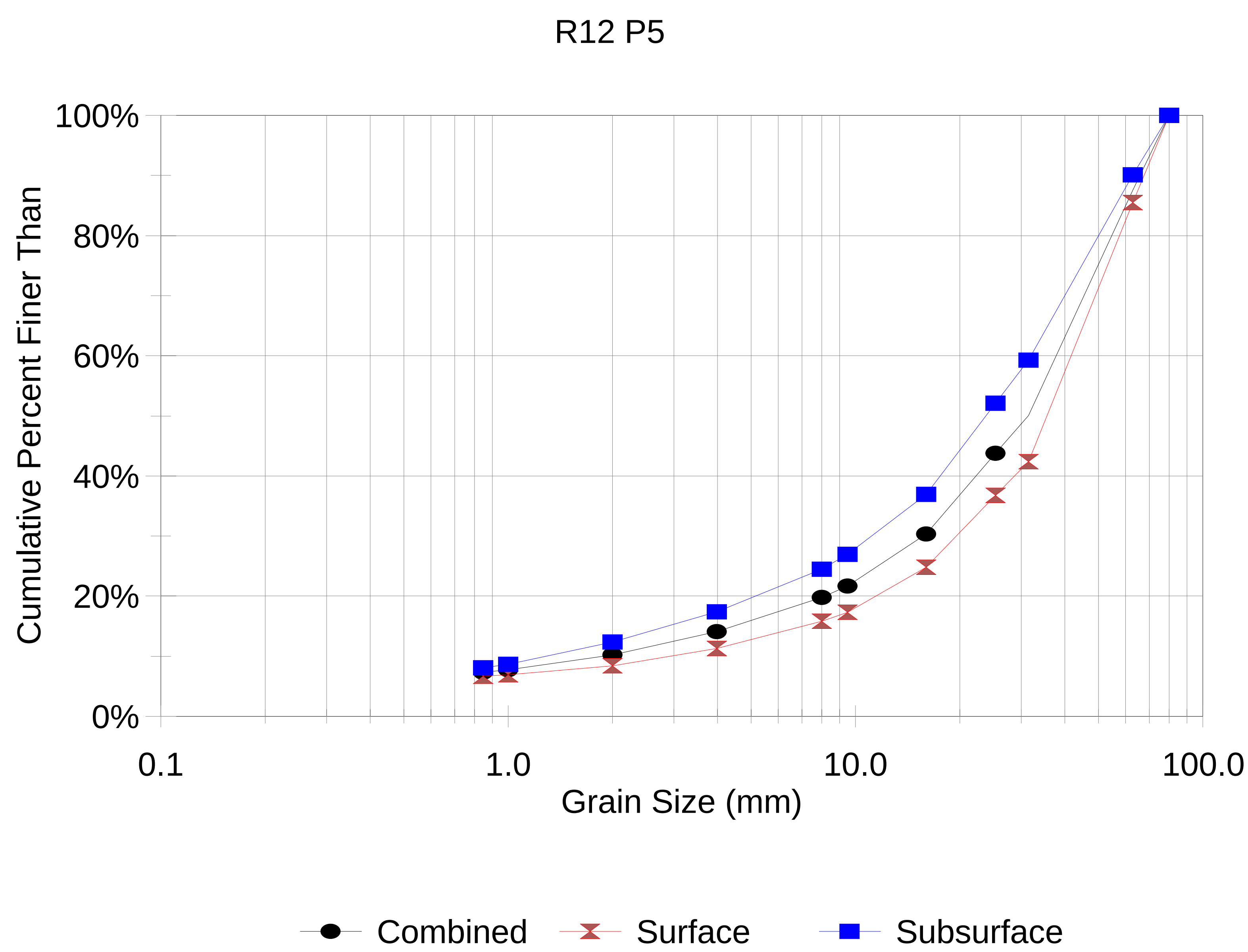
R10 P3
100%
80%
60%
40%
20%
0%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface

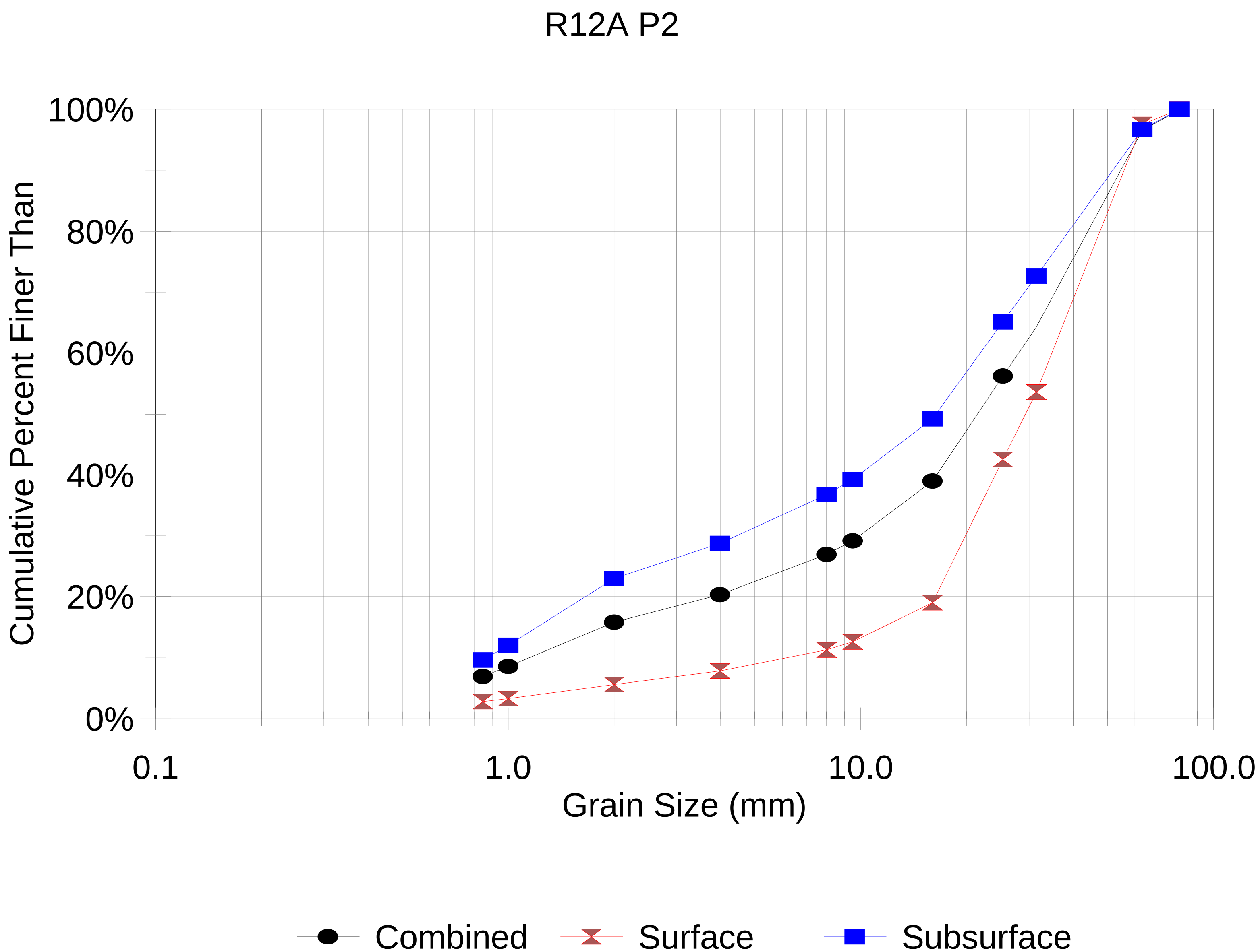

R10 P4
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


R10 P5
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

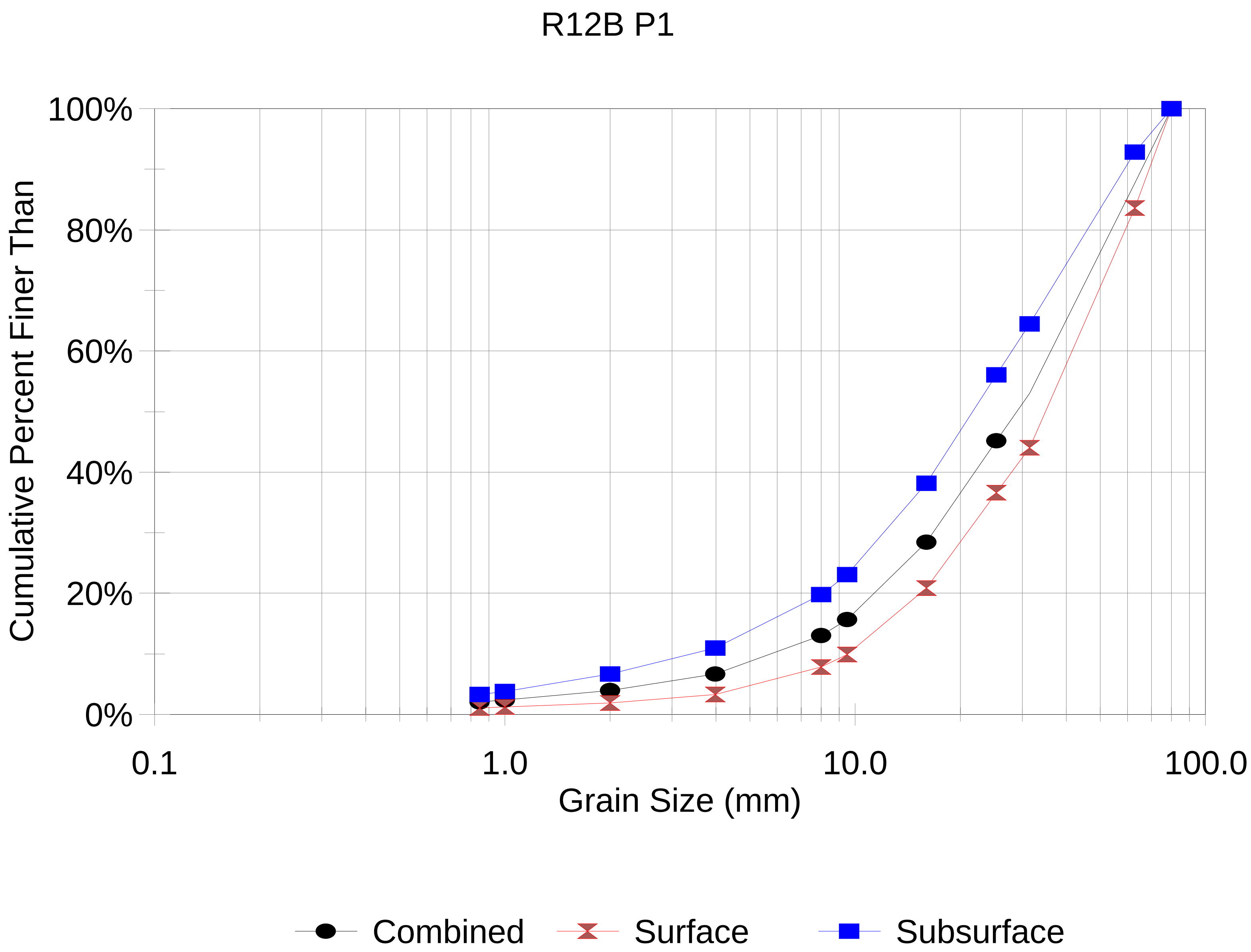


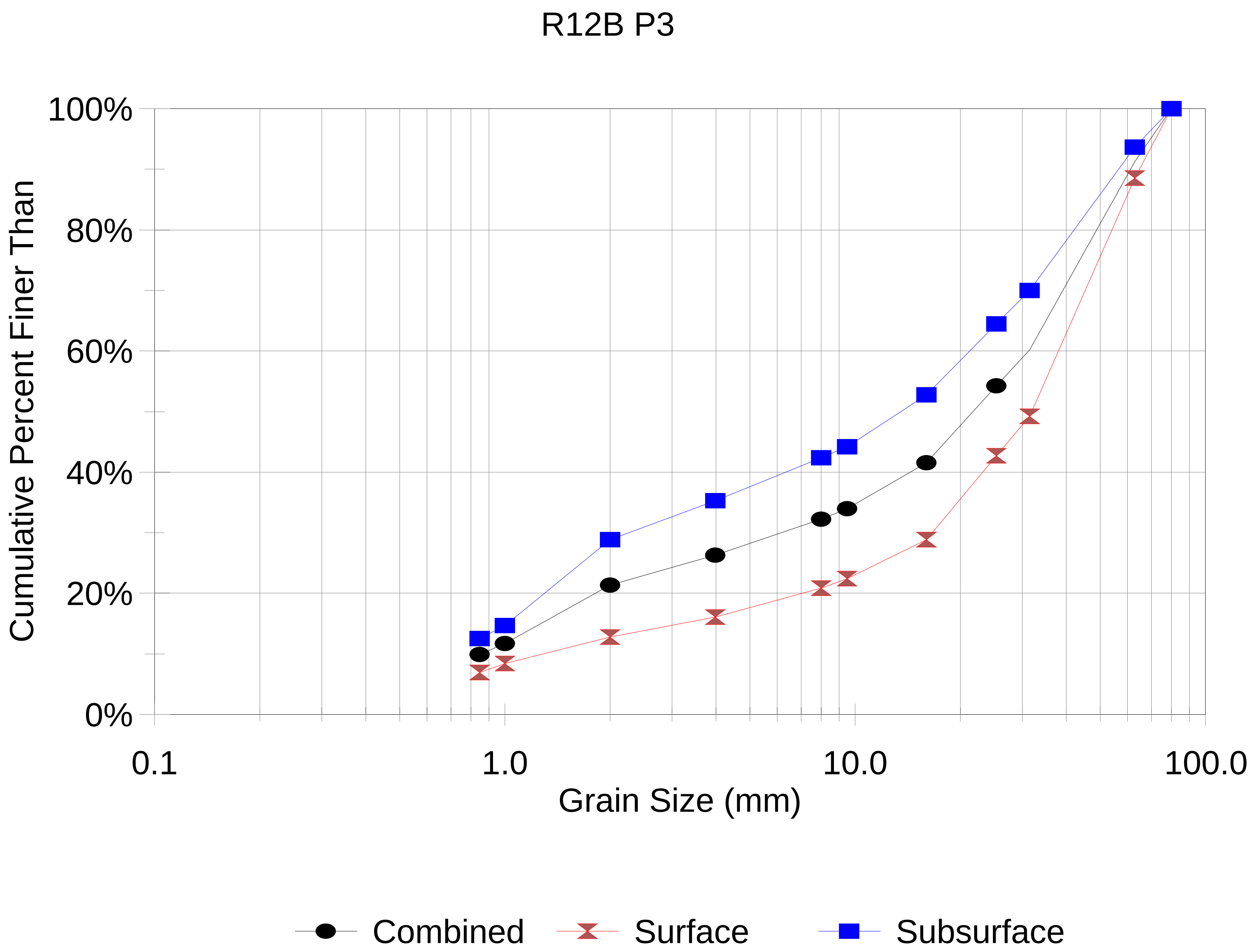
R12 P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


R12 P5
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

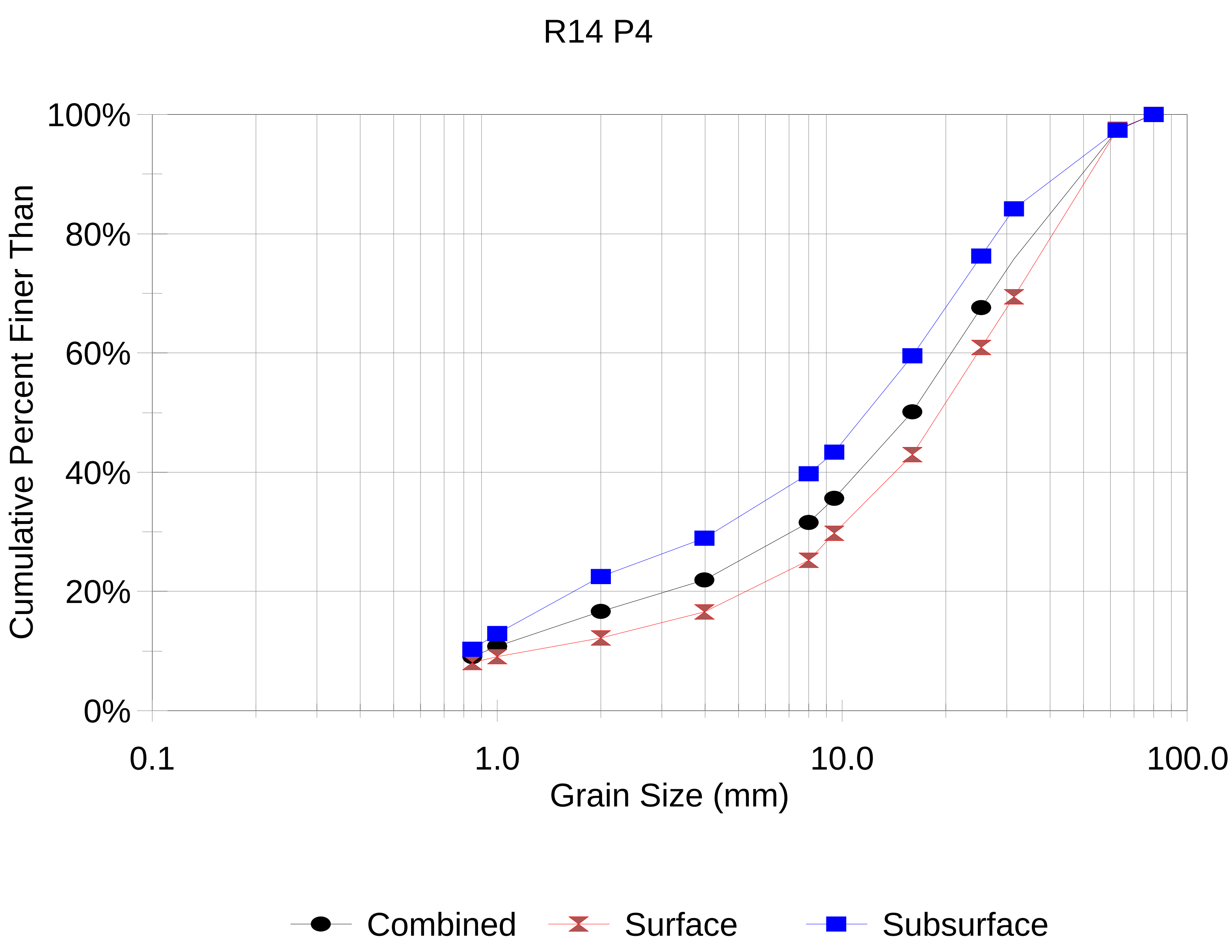


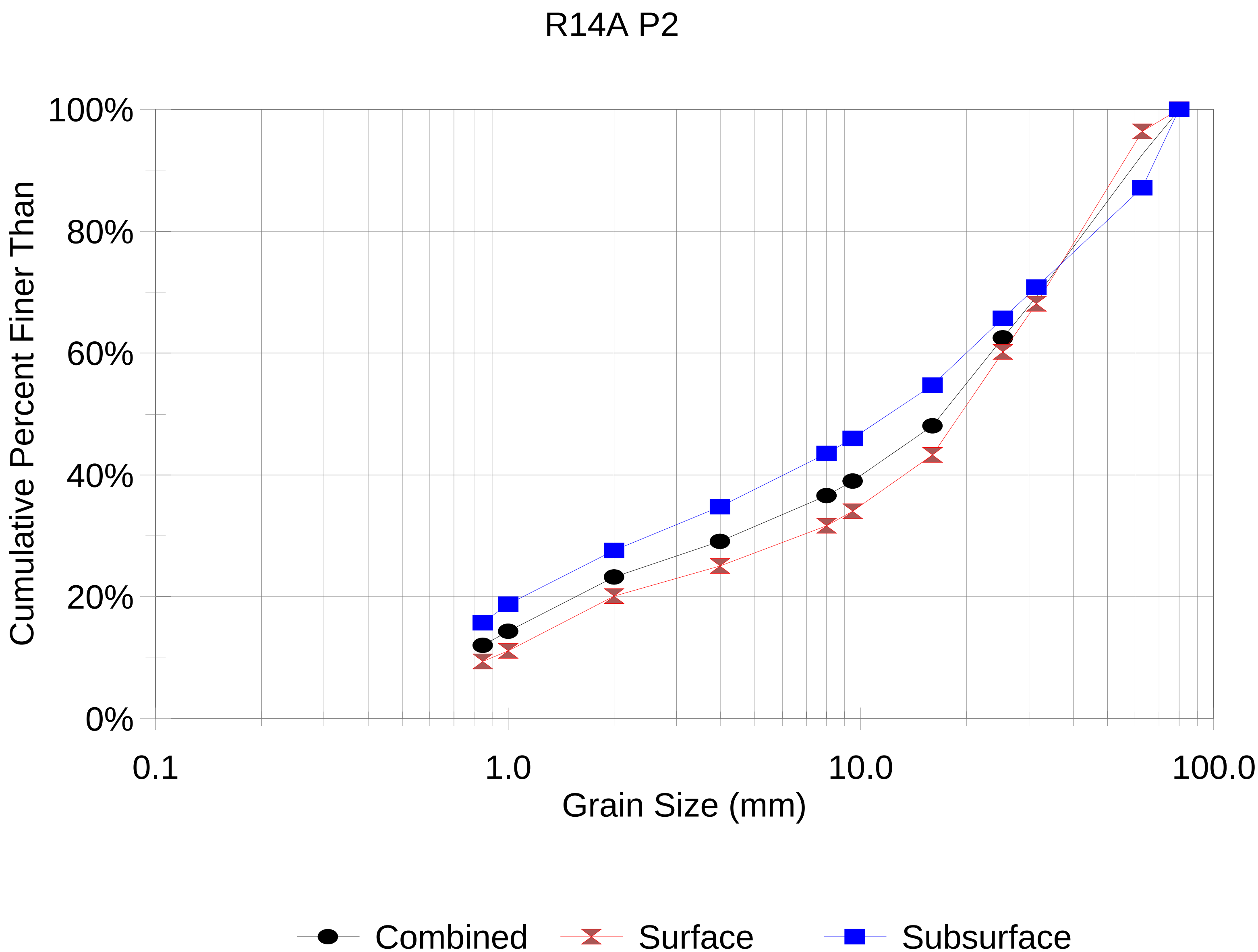
R12A P2
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

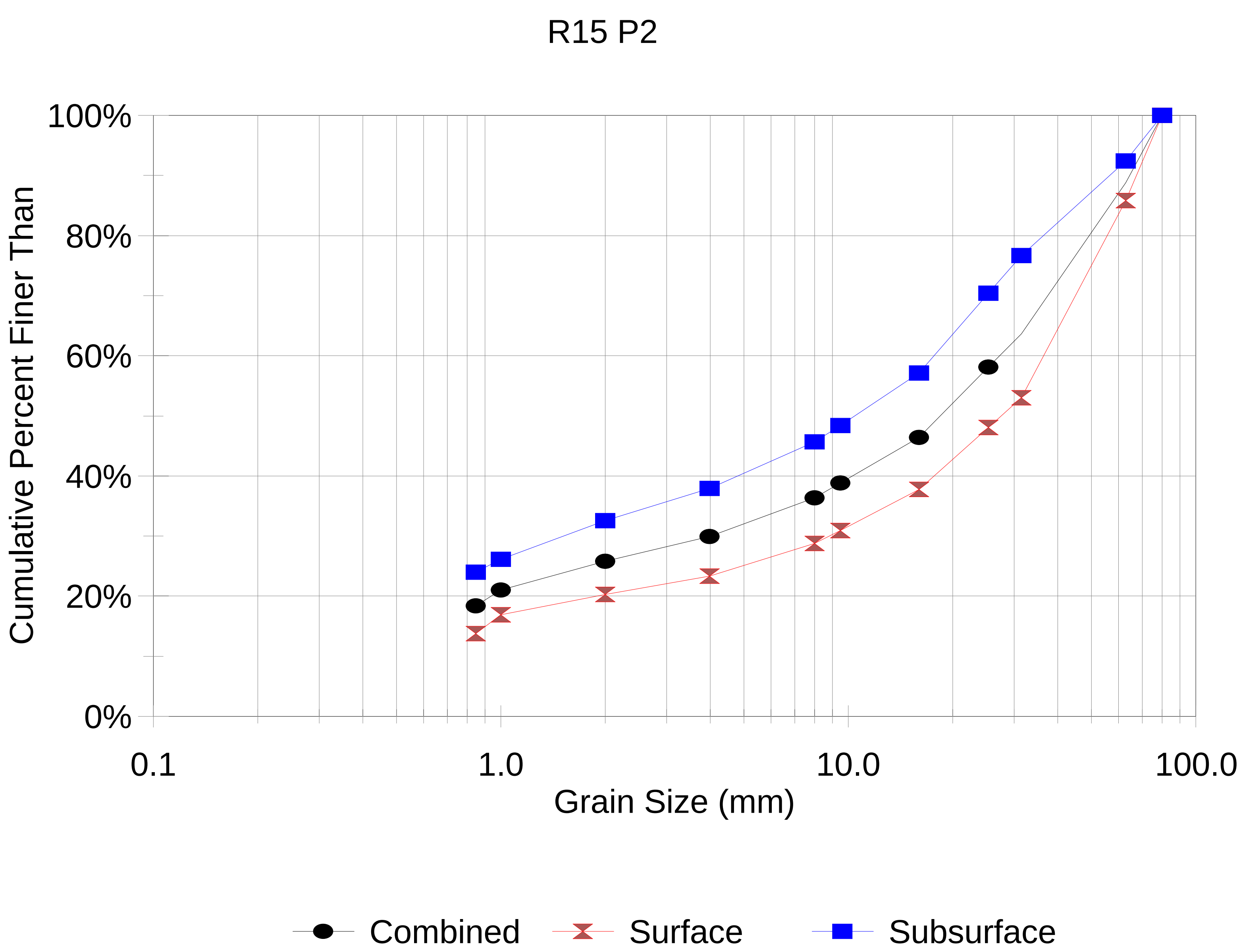

R12B P1
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

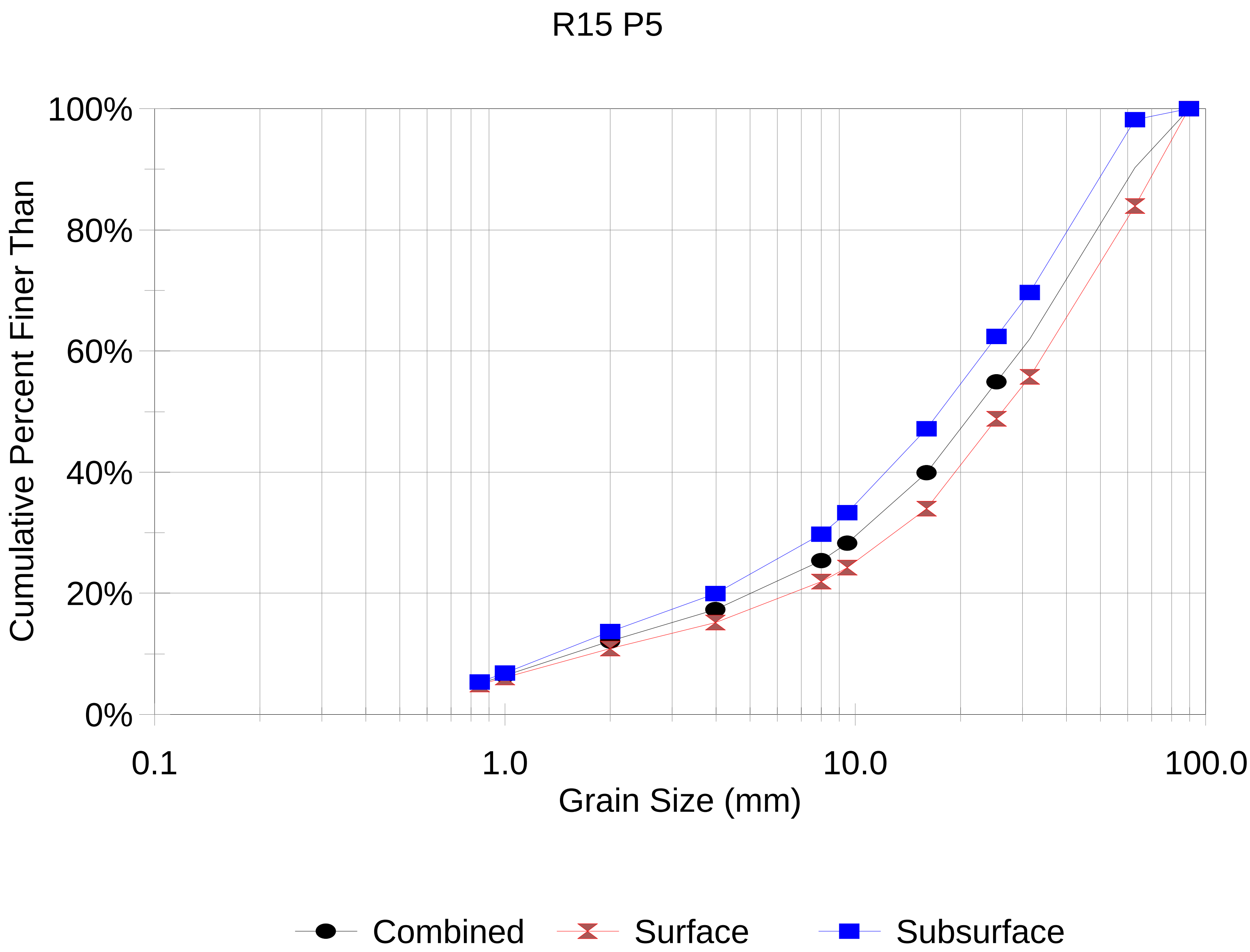


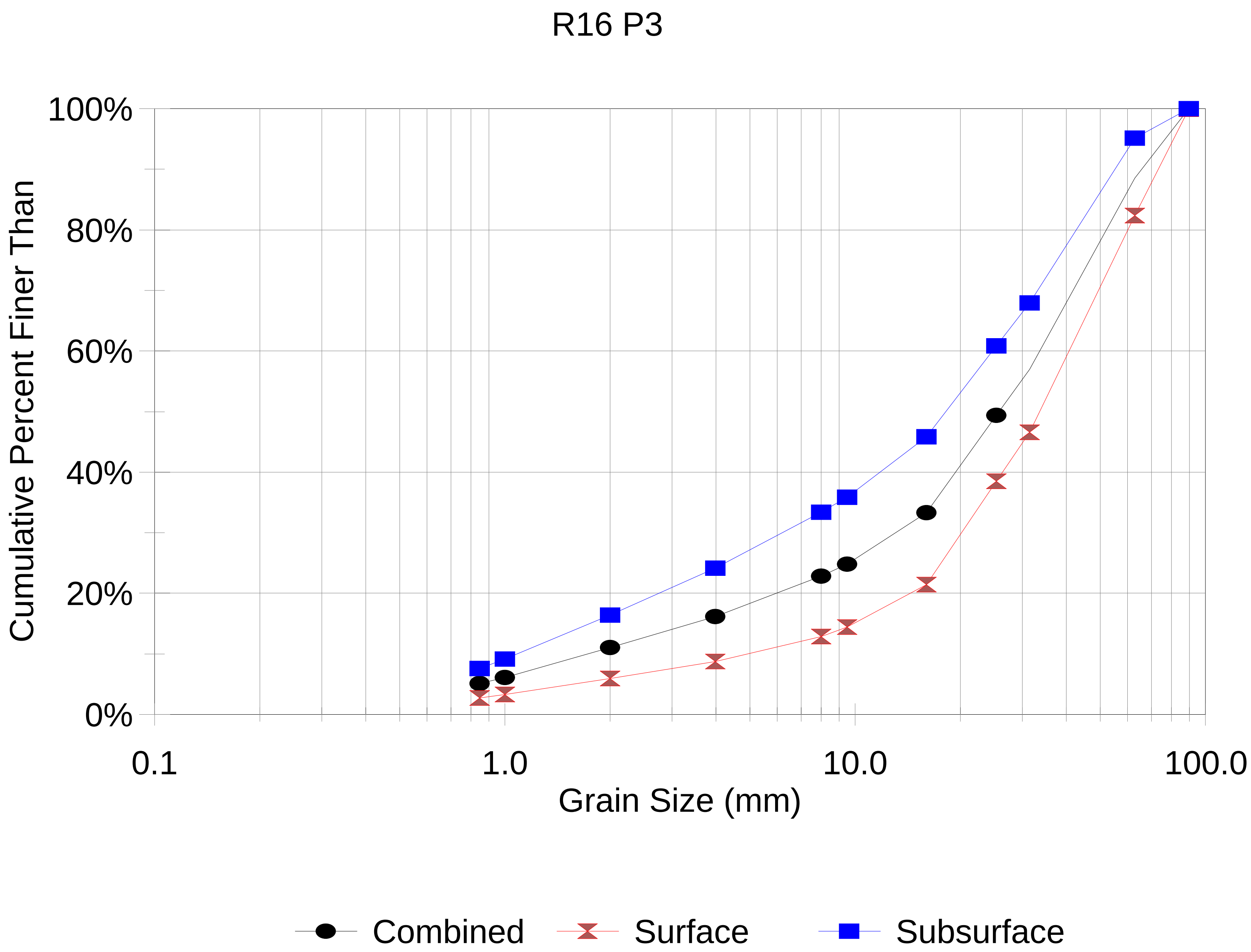
R12B P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


R14 P4
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

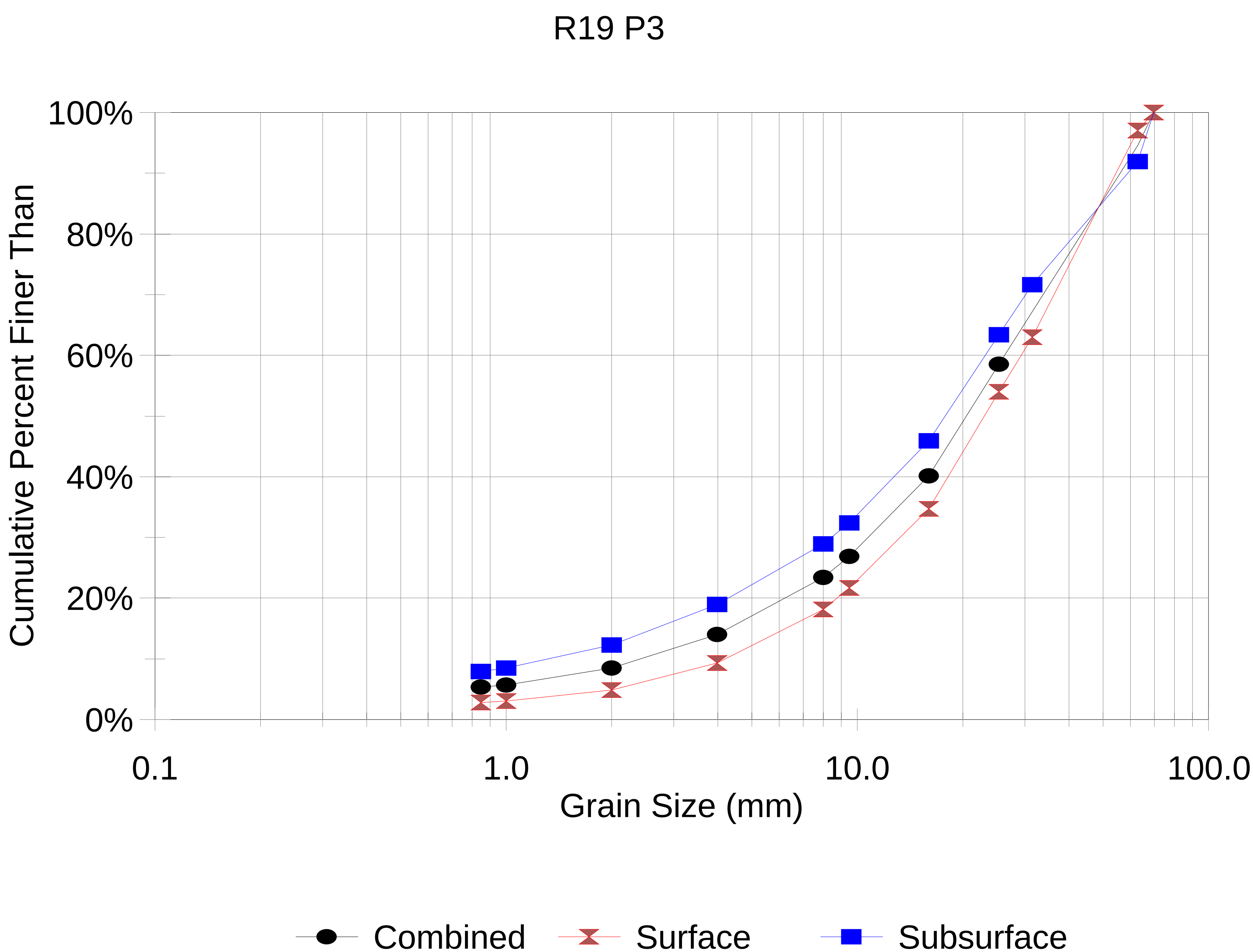

R14A P2
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


R15 P2
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

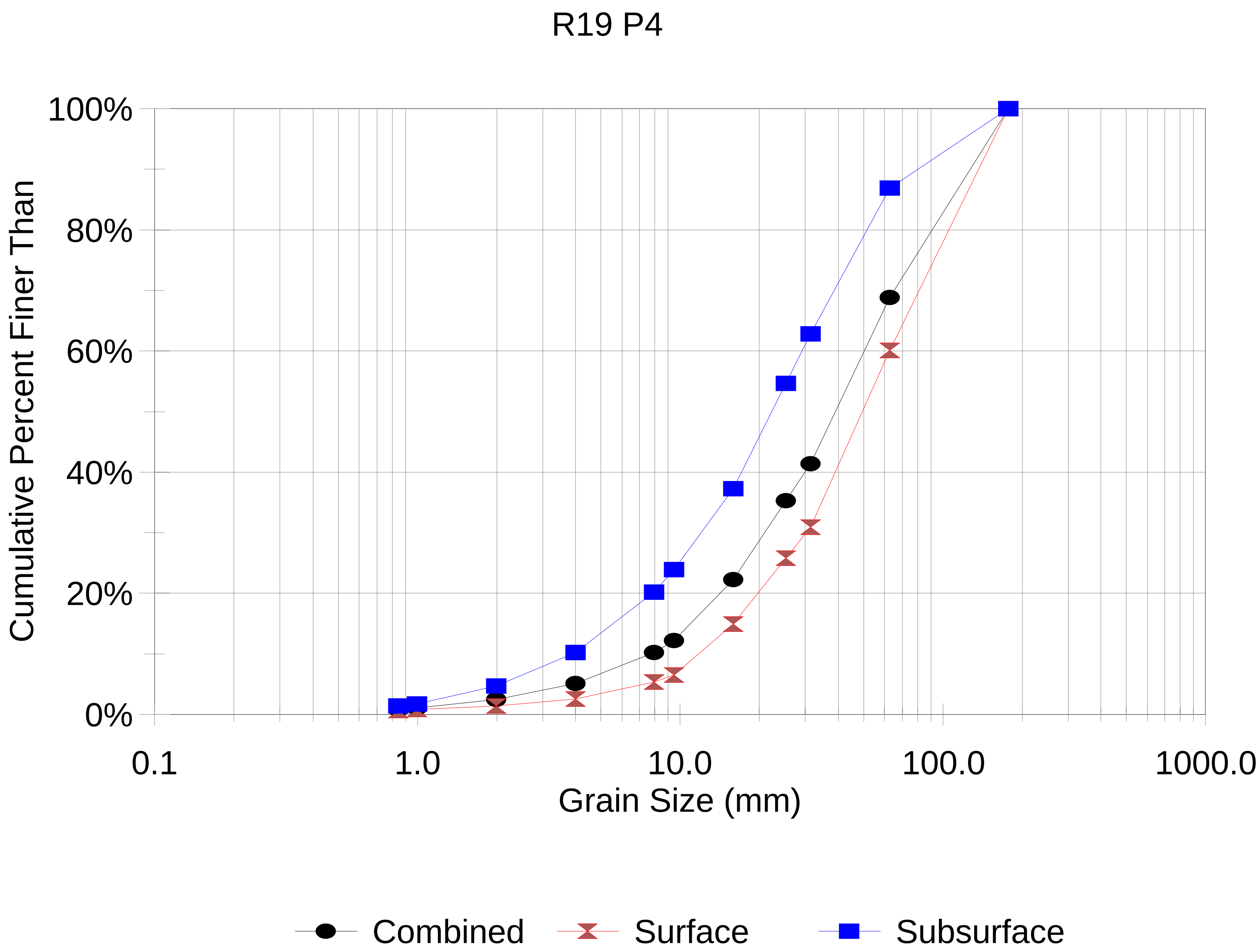

R15 P5
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

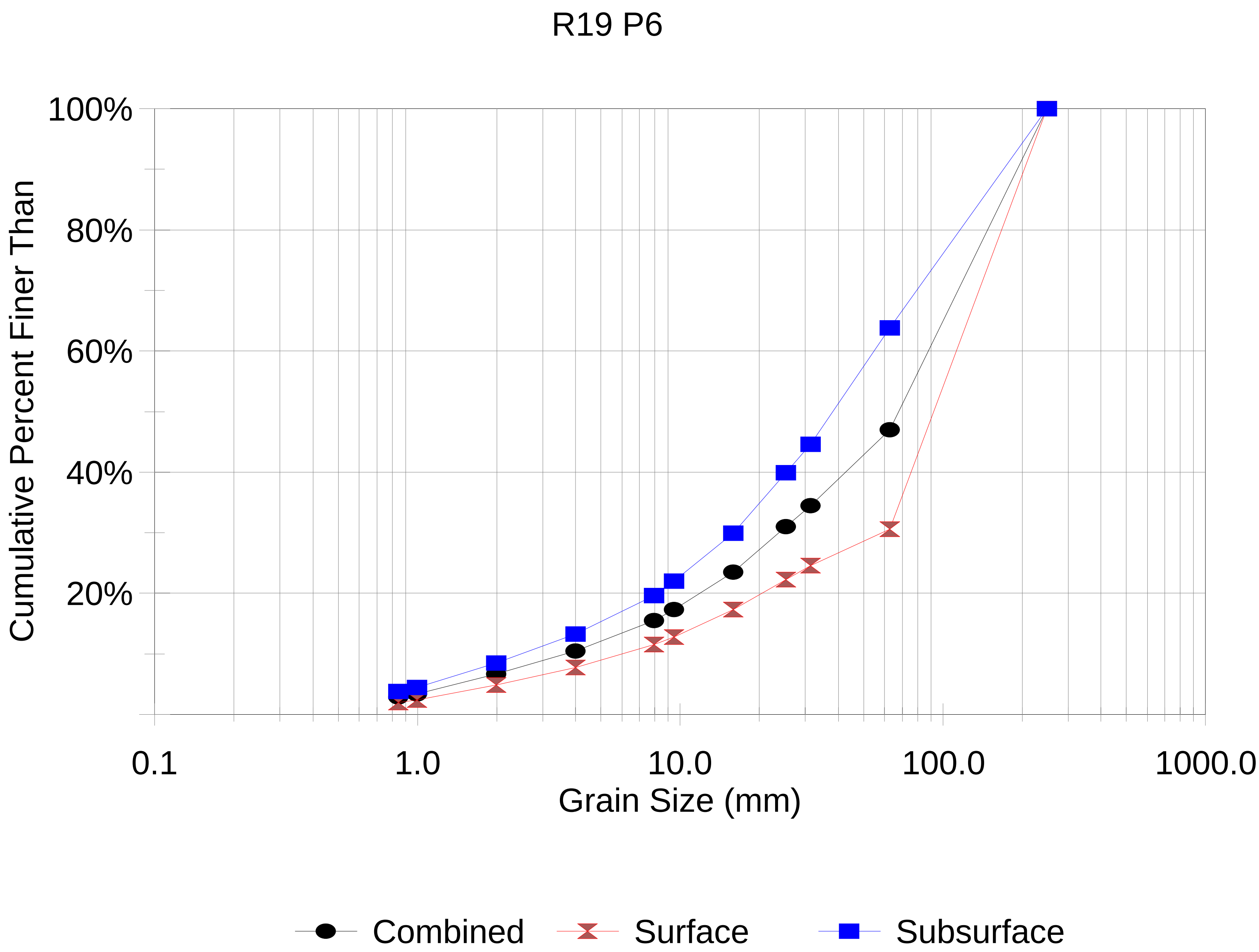


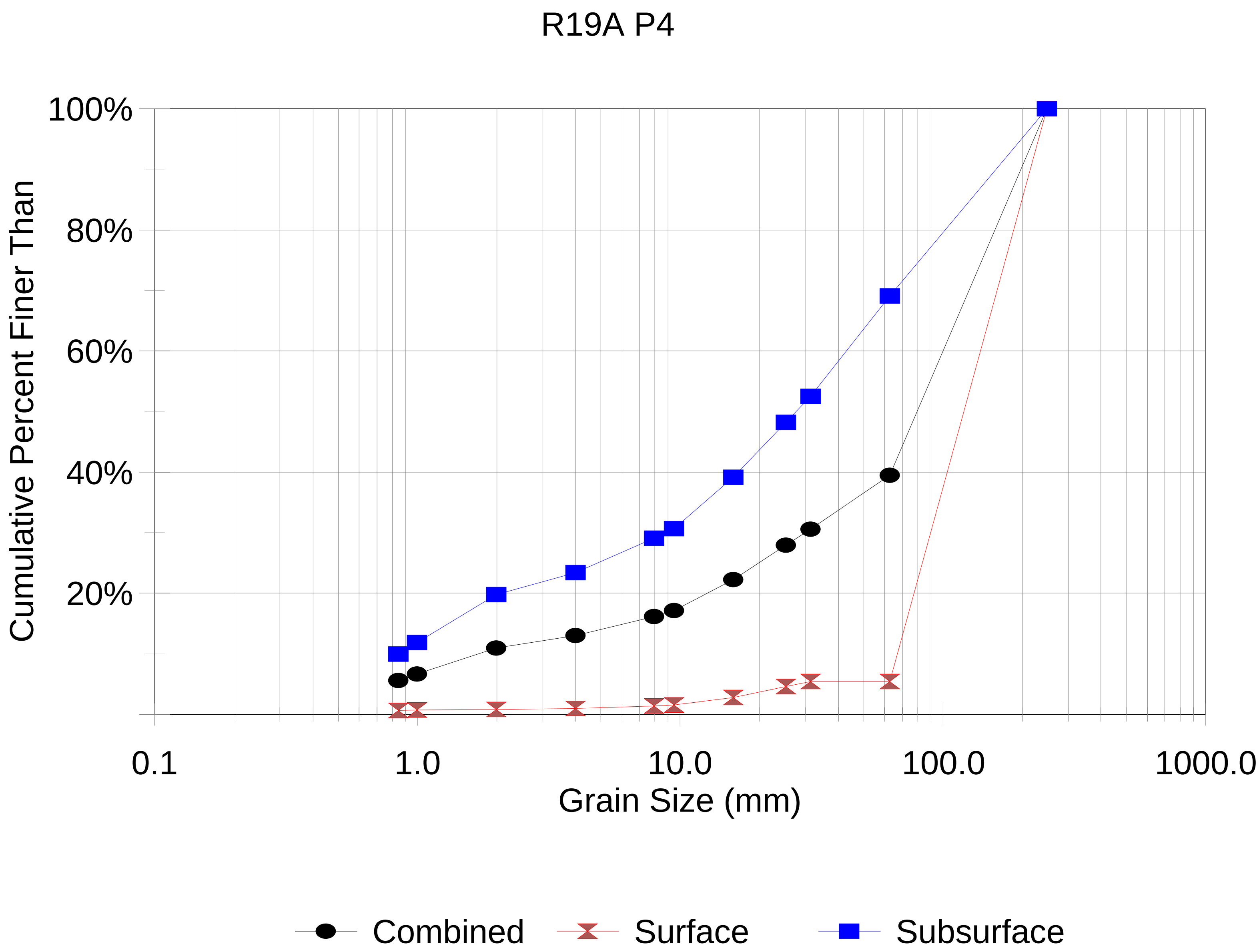
R16 P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

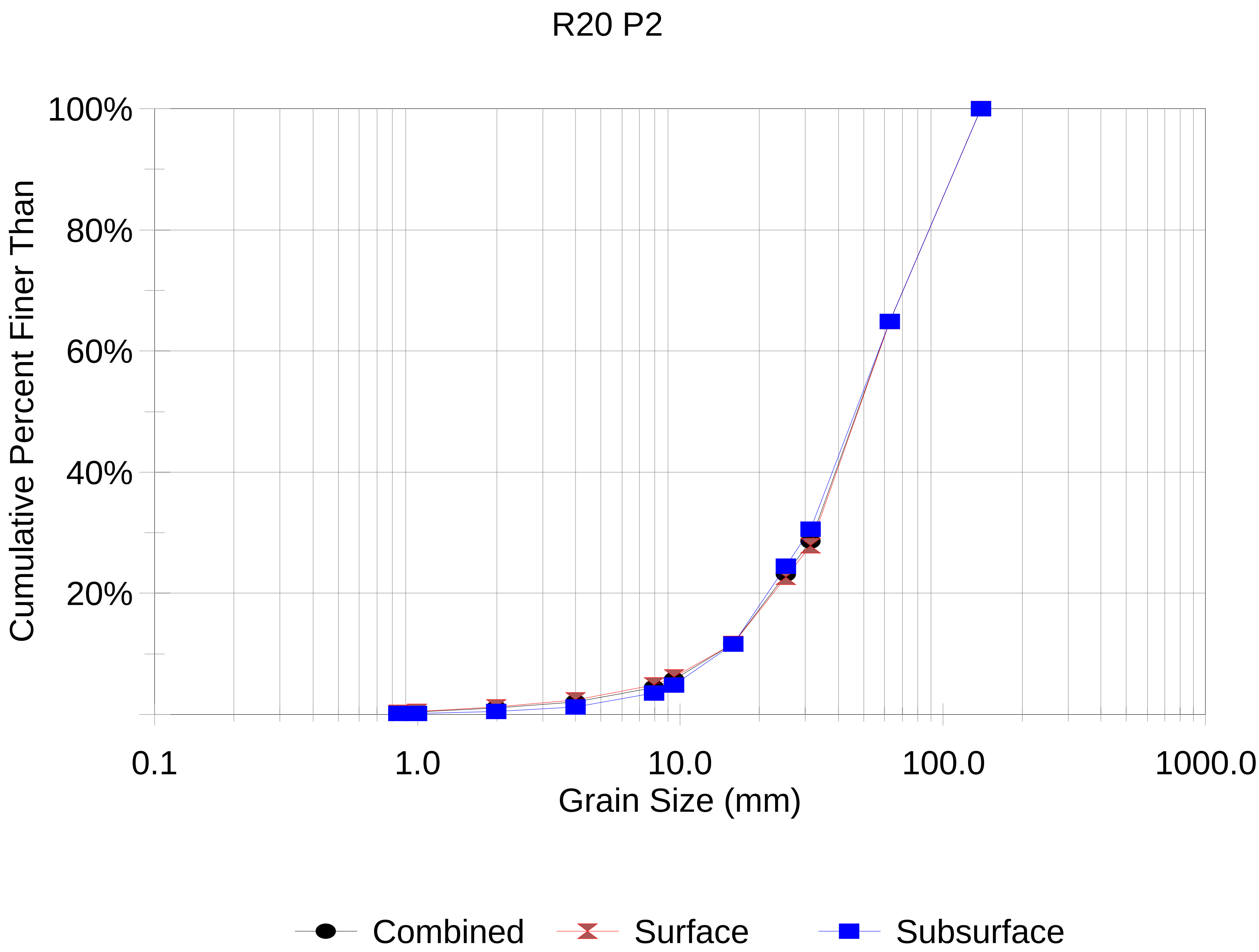


R19 P3
100%
80%
60%
40%
20%
0%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

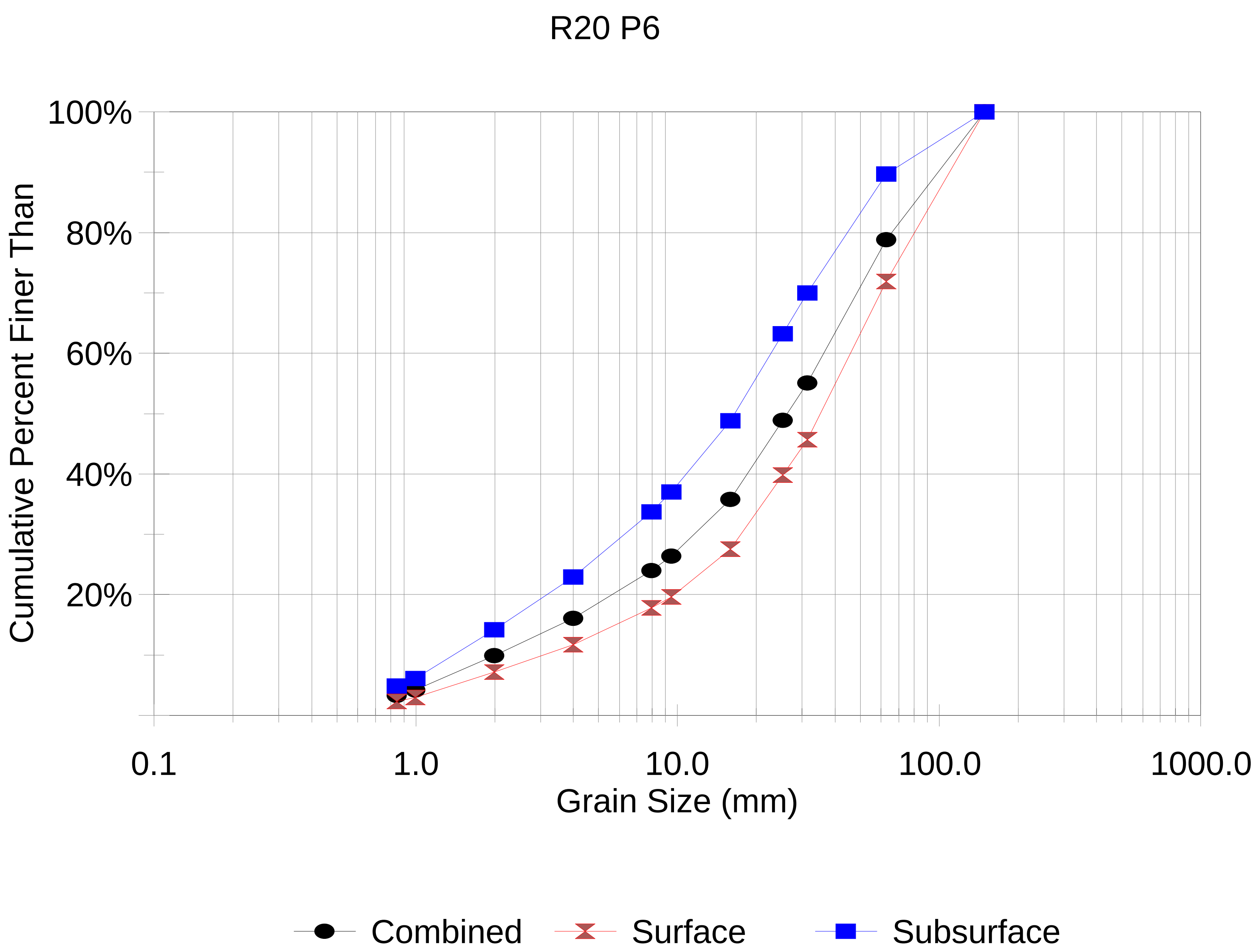

R19 P4
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface

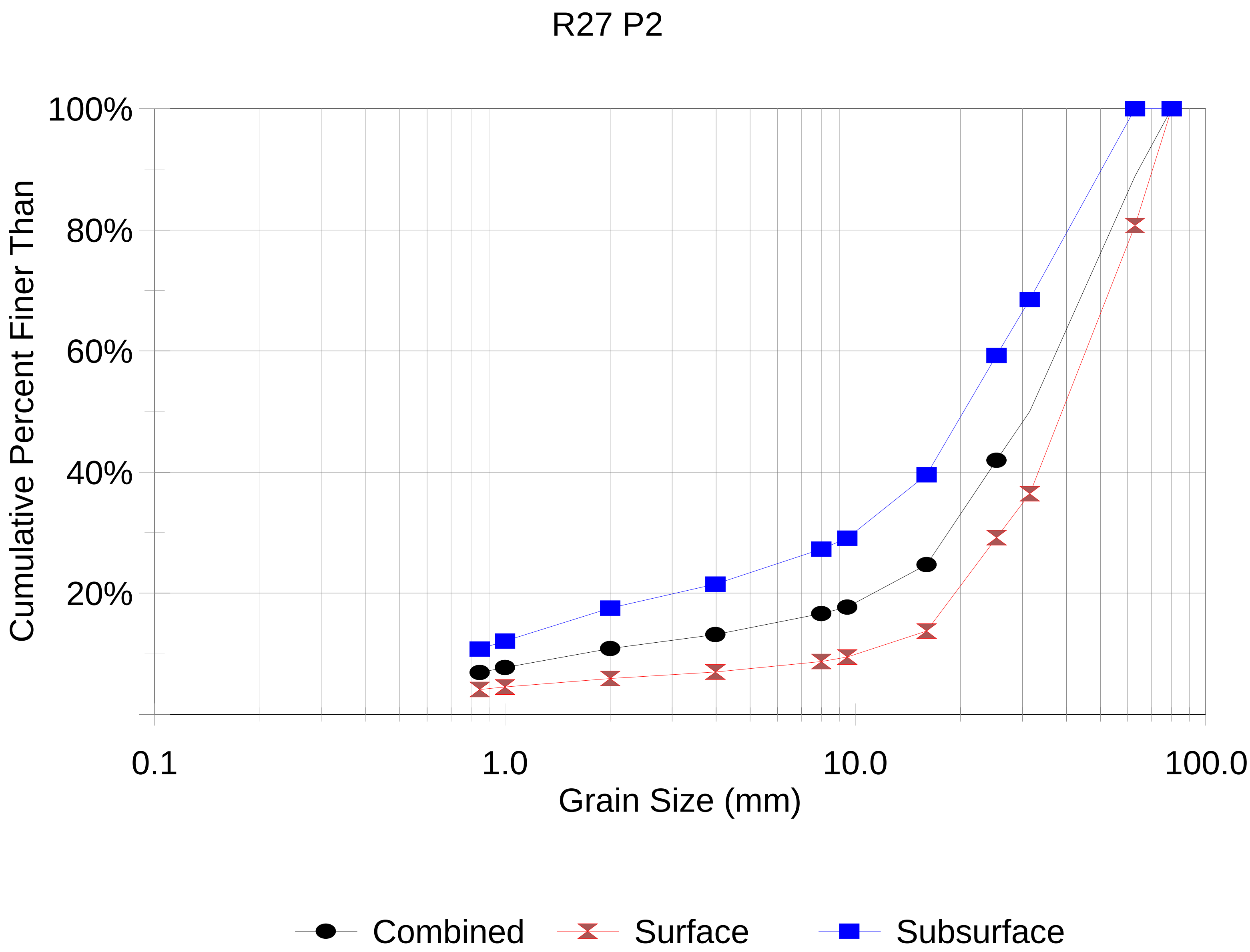

R19 P6
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface


R19A P4
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface

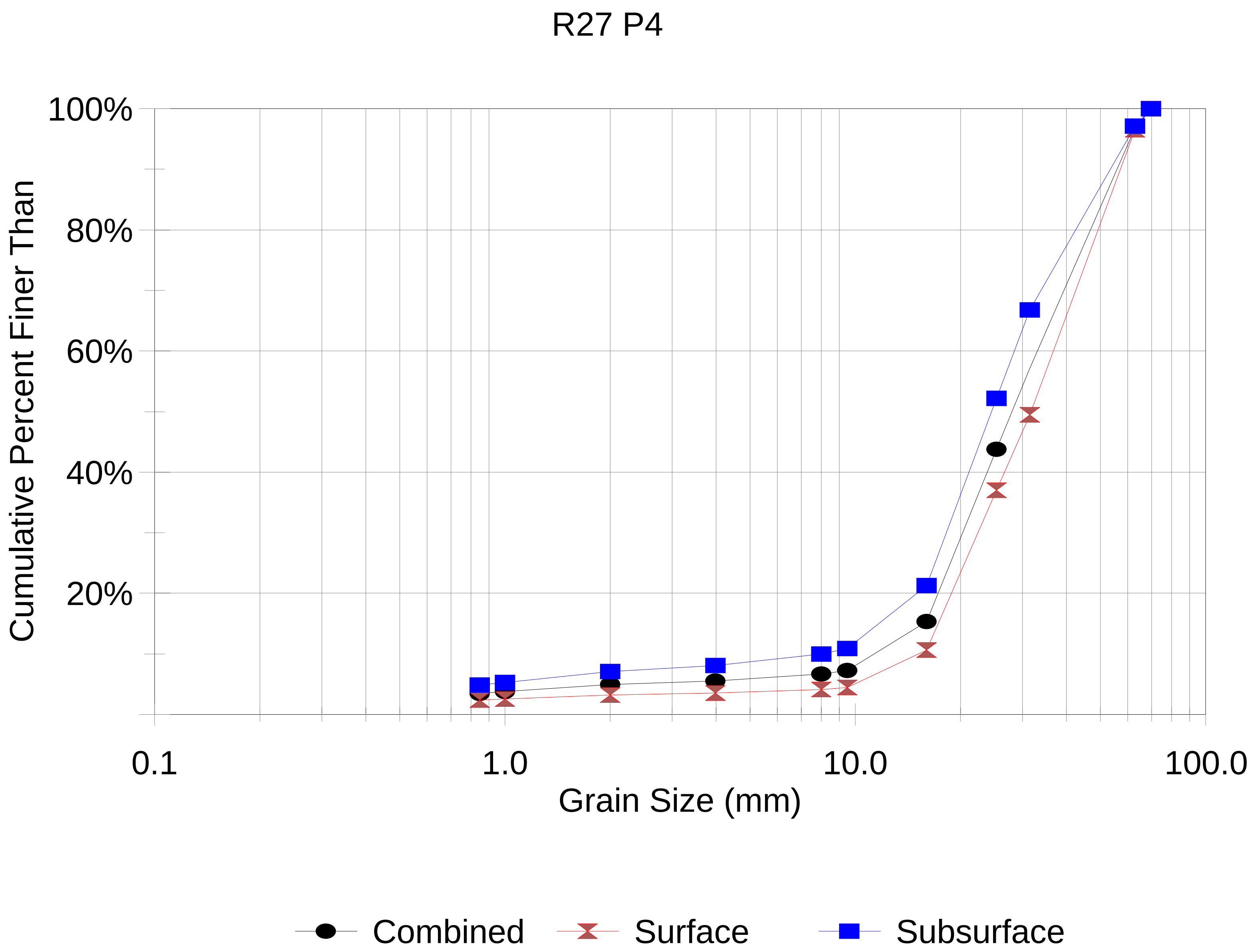


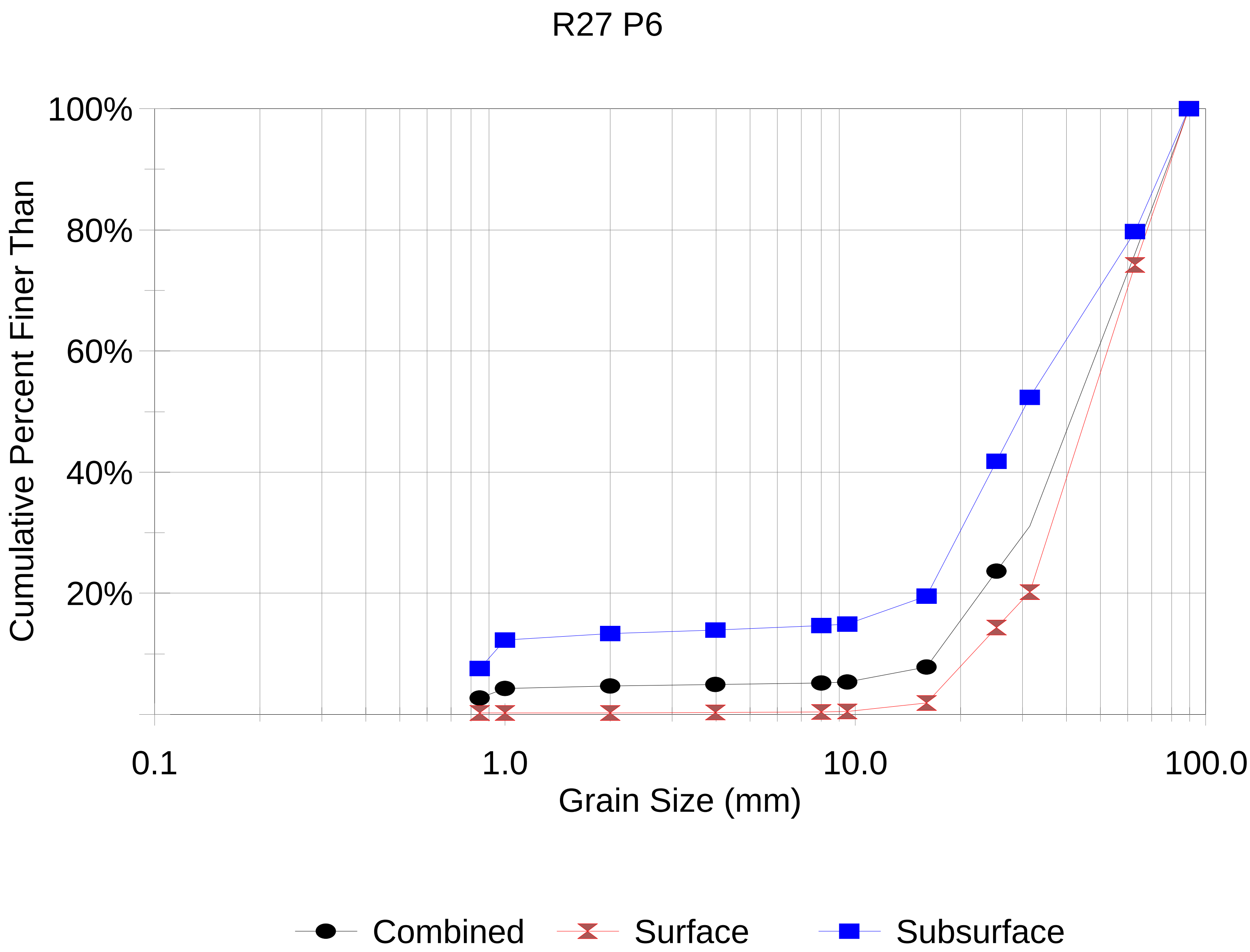
R20 P2
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface

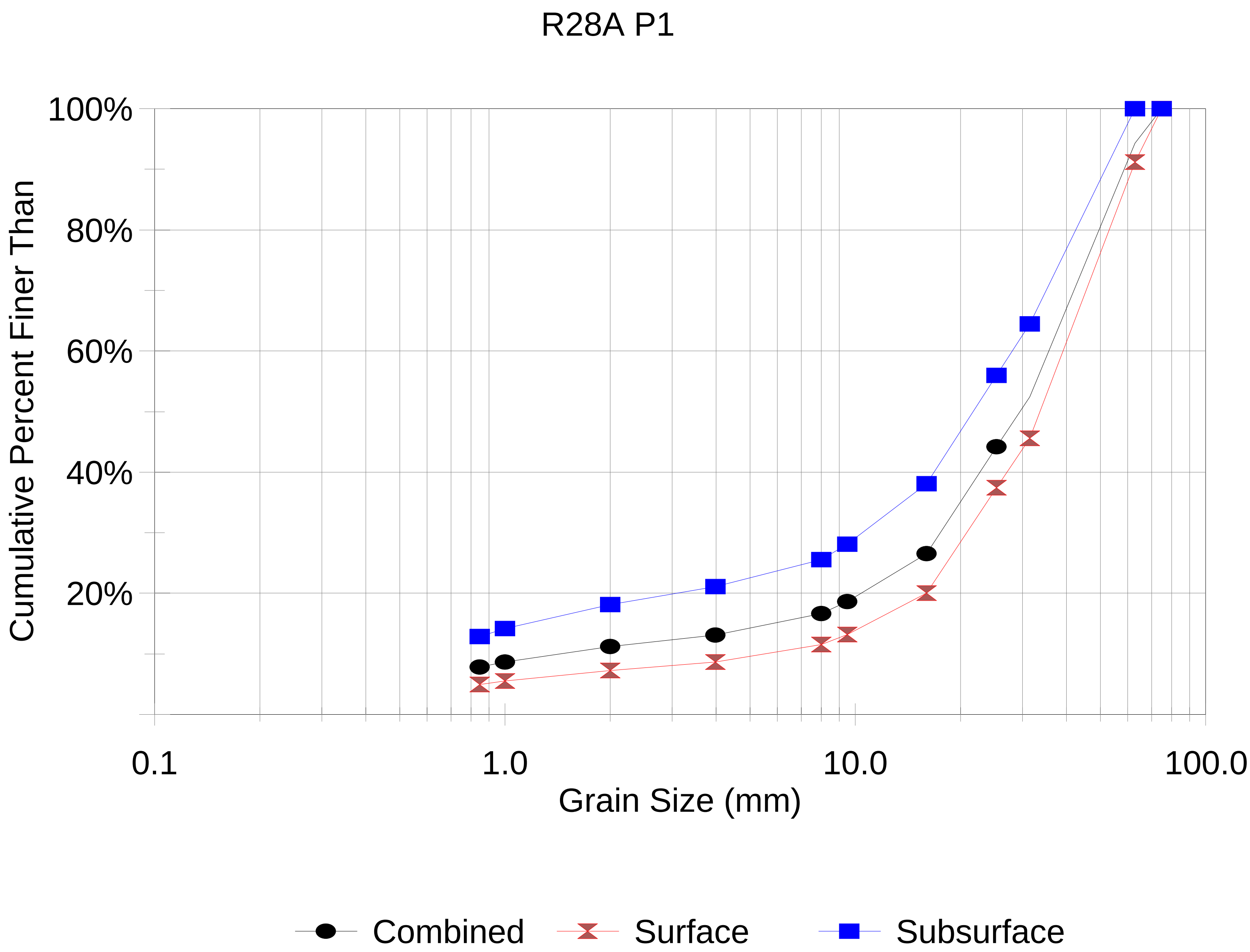

R20 P6
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface



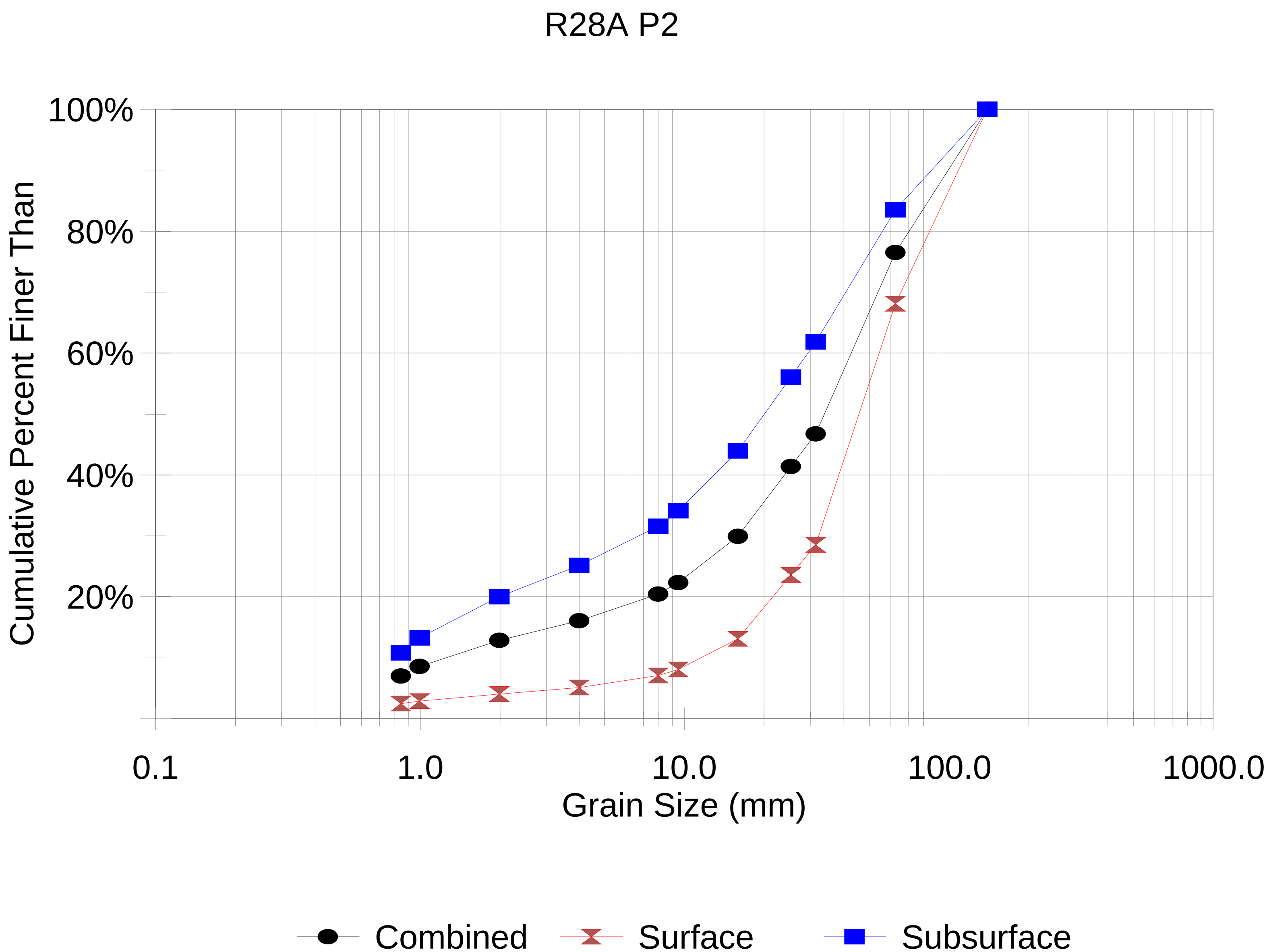
R27 P2
100%
80%
60%
40%
20%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

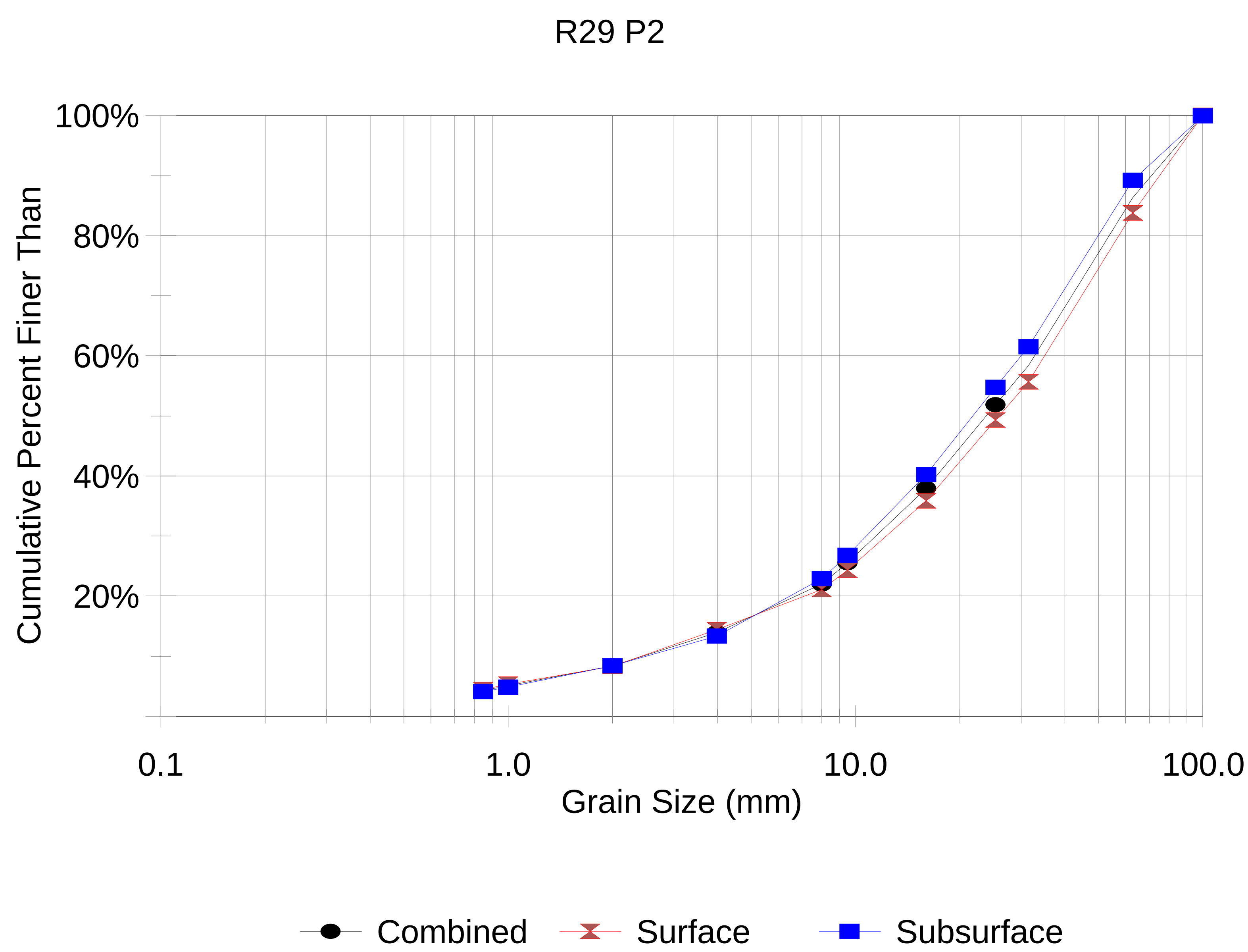

R27 P4
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

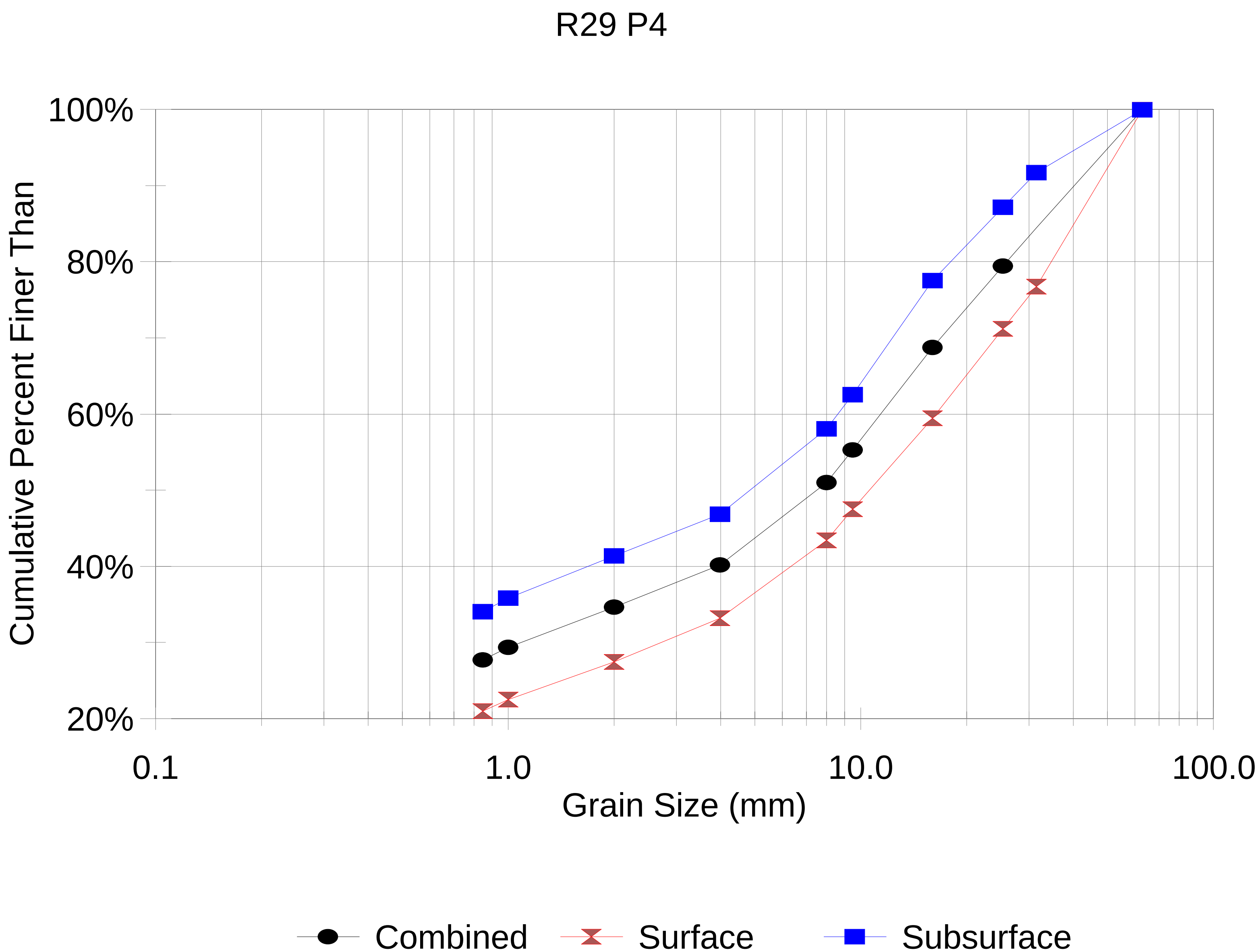

R27 P6
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

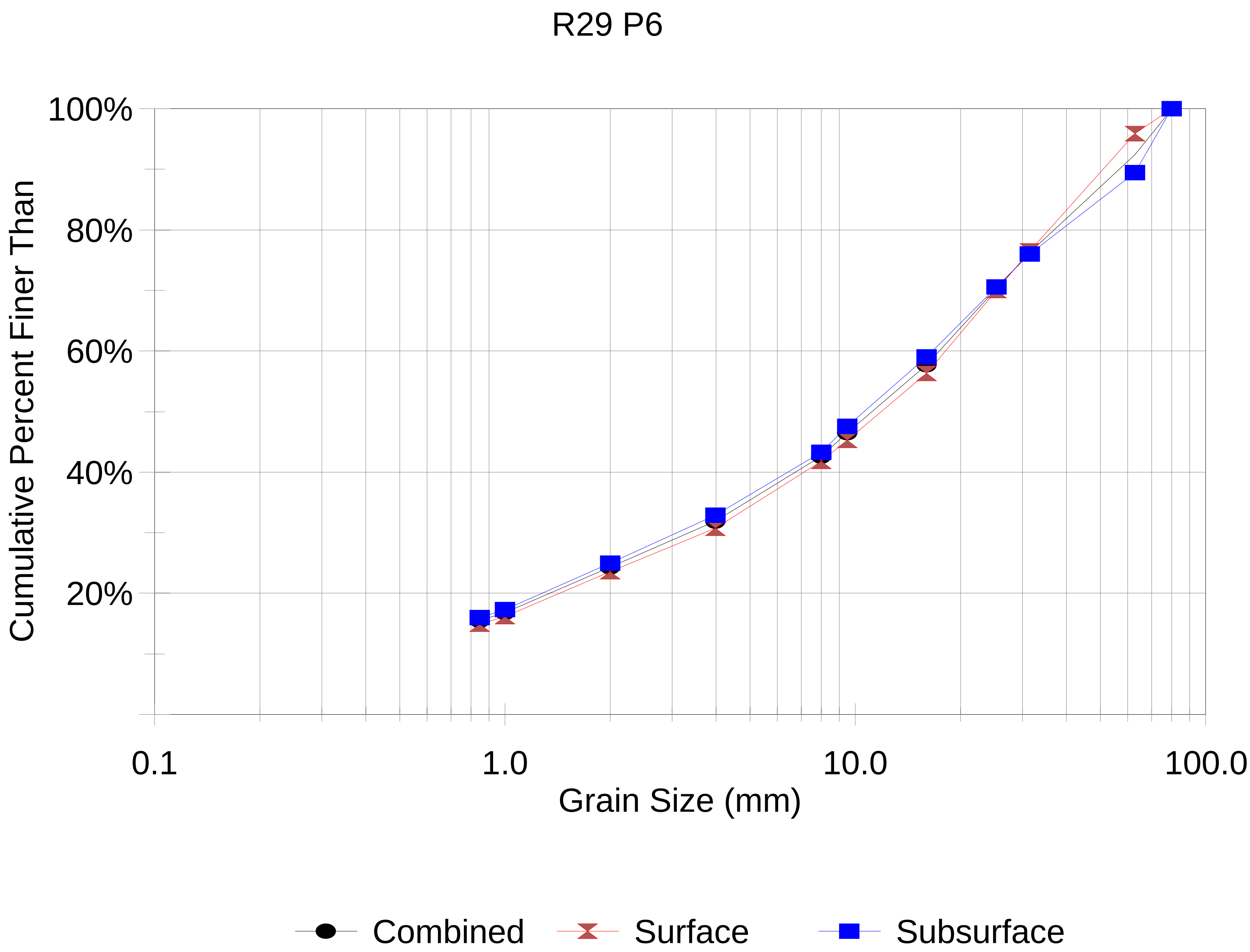


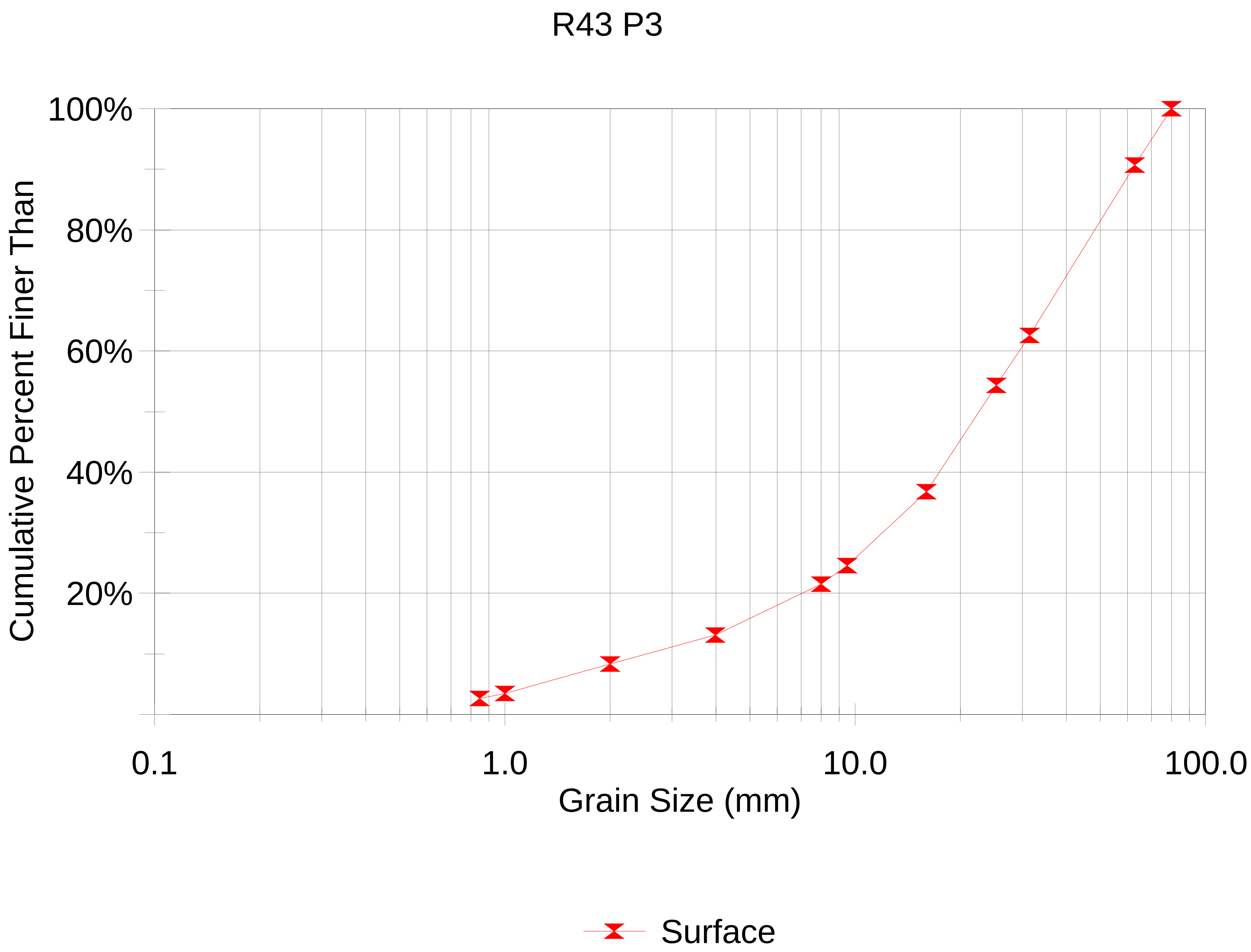
R28A P1
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

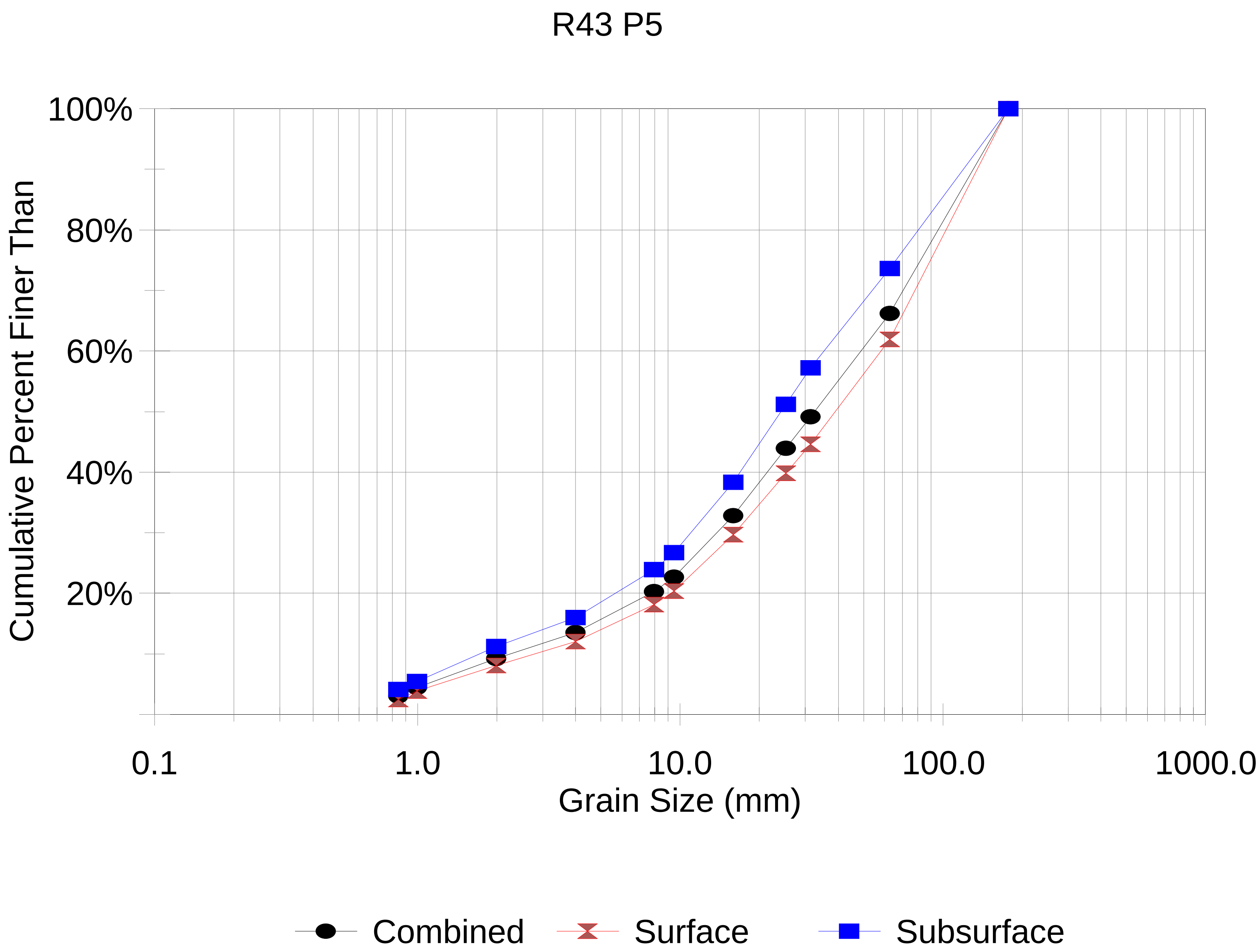

R28A P2
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface

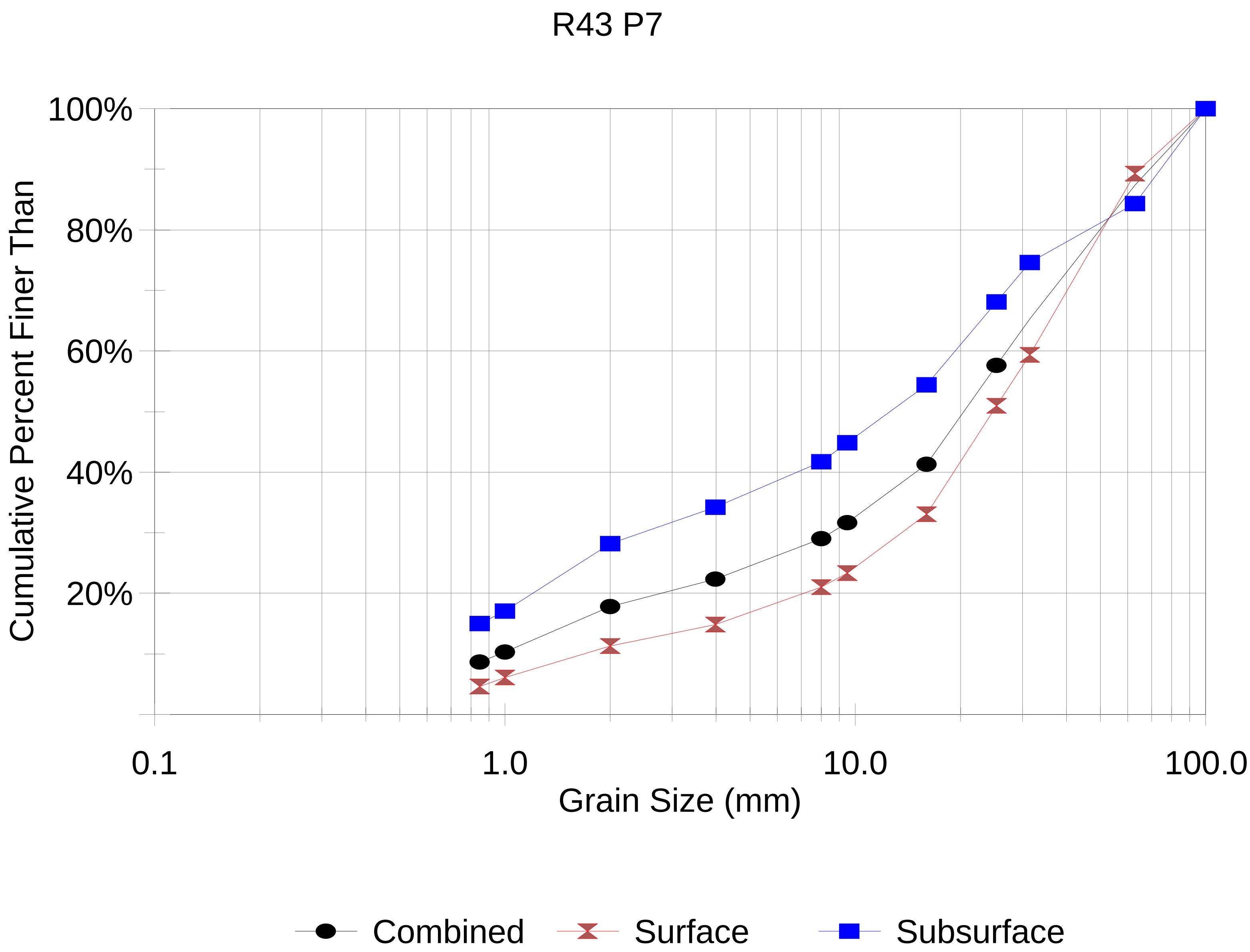

R29 P2
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

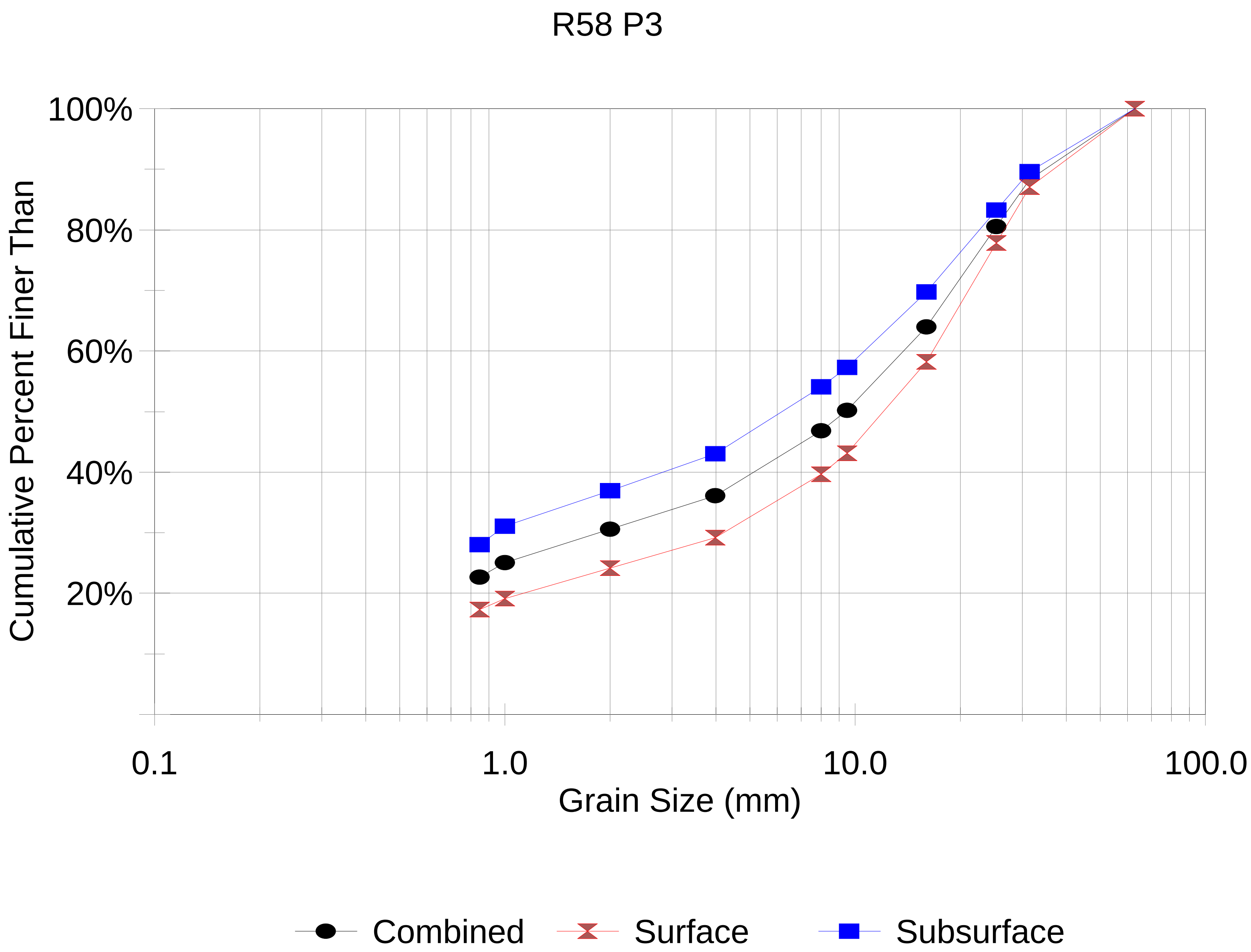

R29 P4
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


R29 P6
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

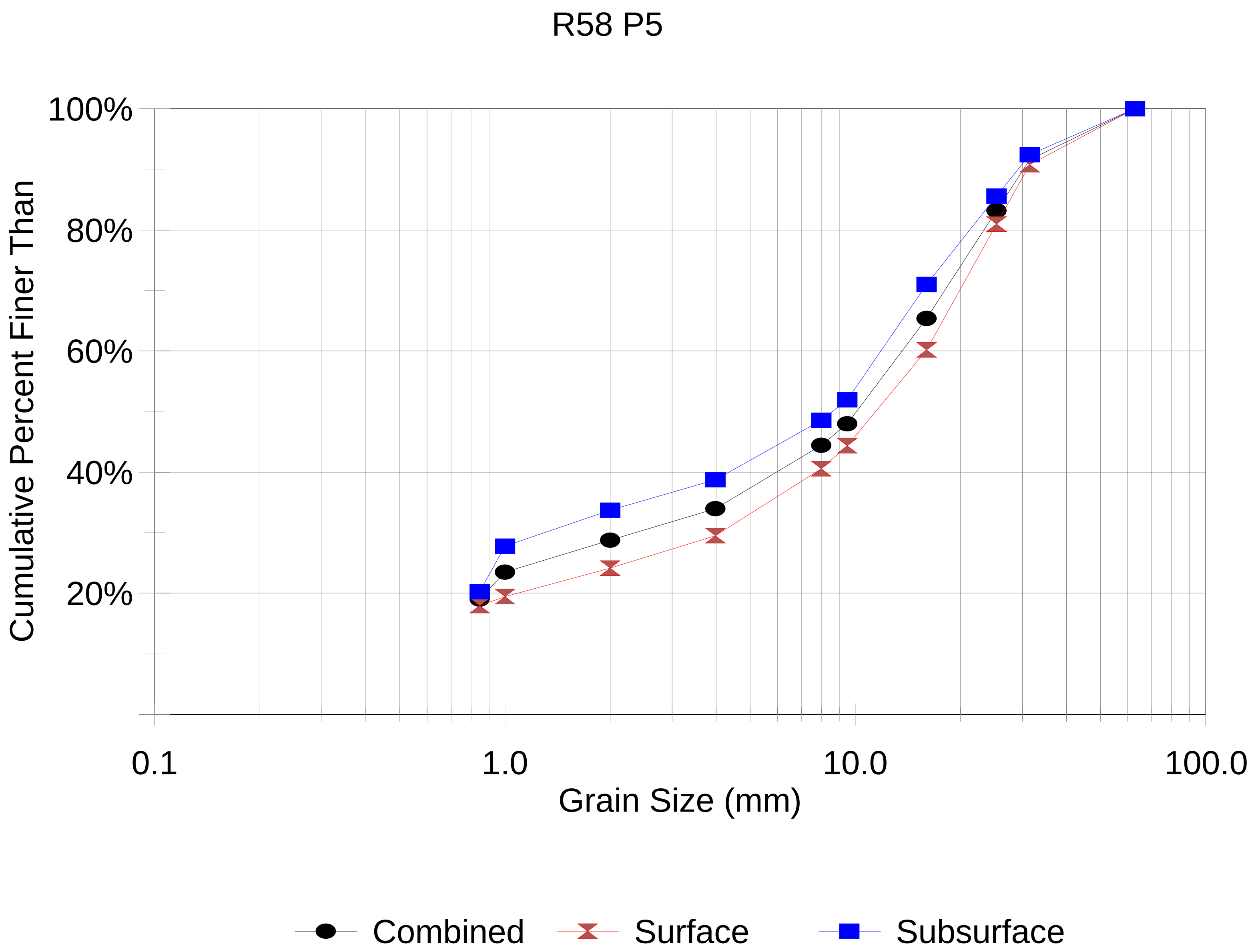

R43 P3
100%
80%
60%
40%
20%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Surface

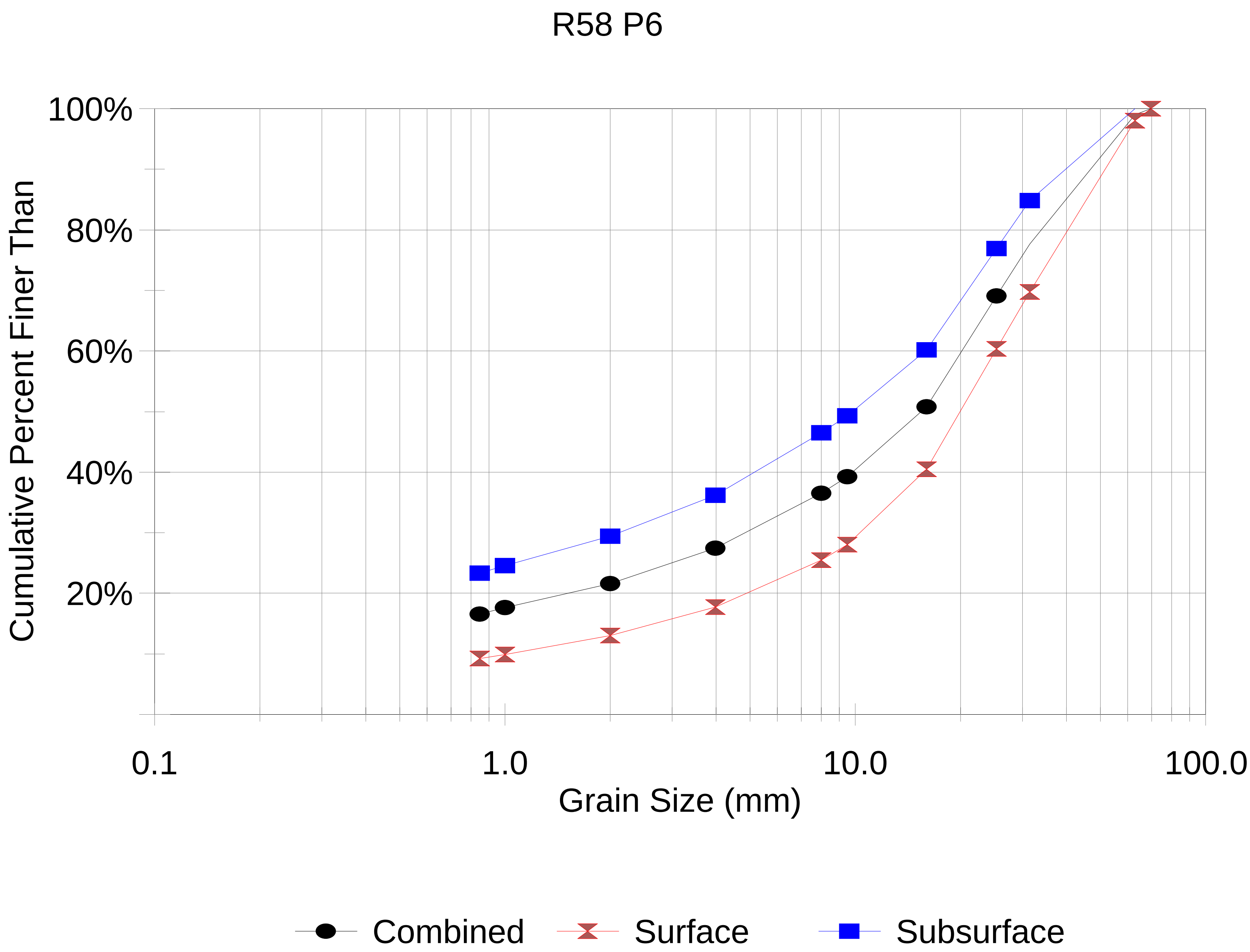

R43 P5
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
1000.0
Grain Size (mm)
Combined
Surface
Subsurface


R43 P7
100%
80%
60%
40%
20%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

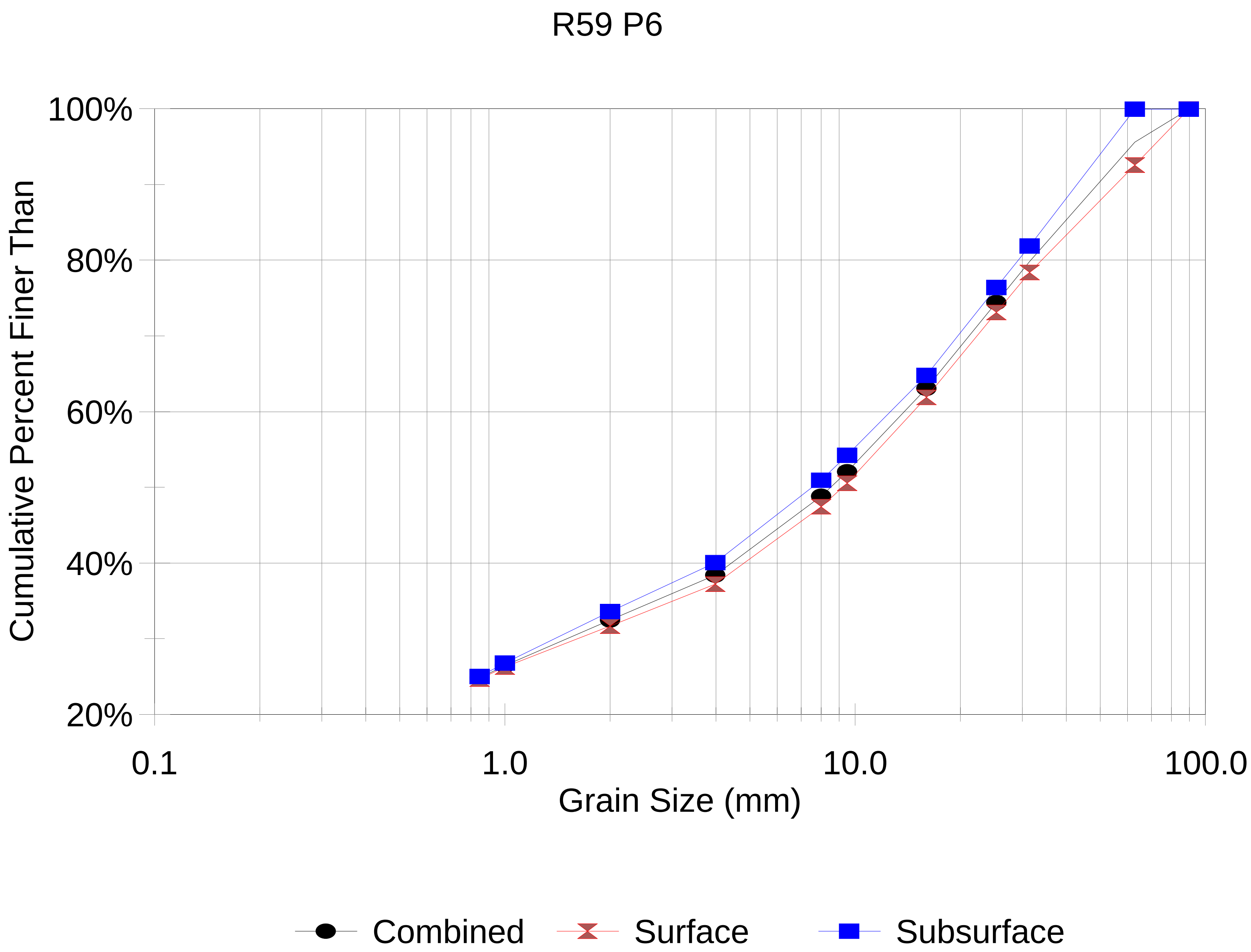


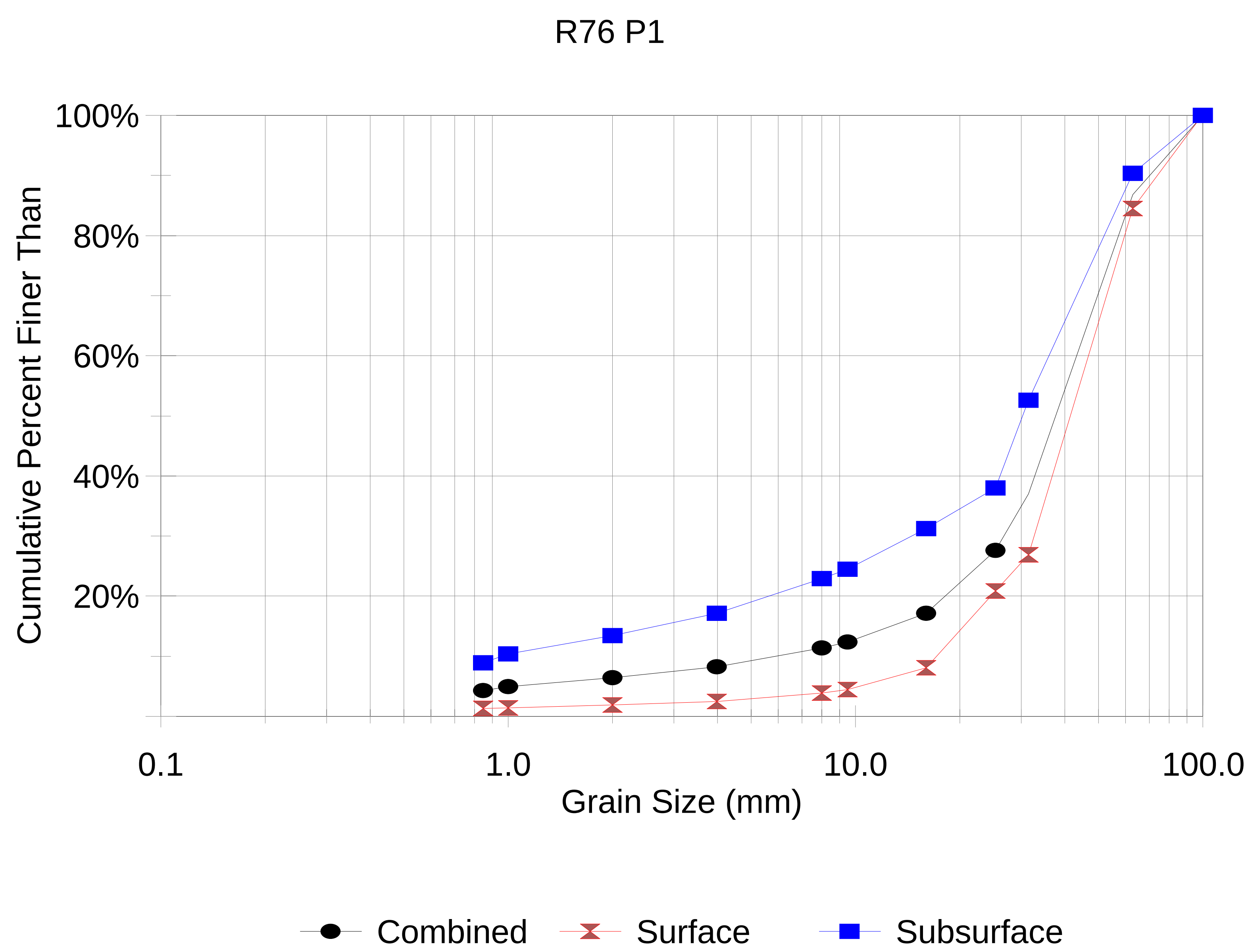
R58 P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

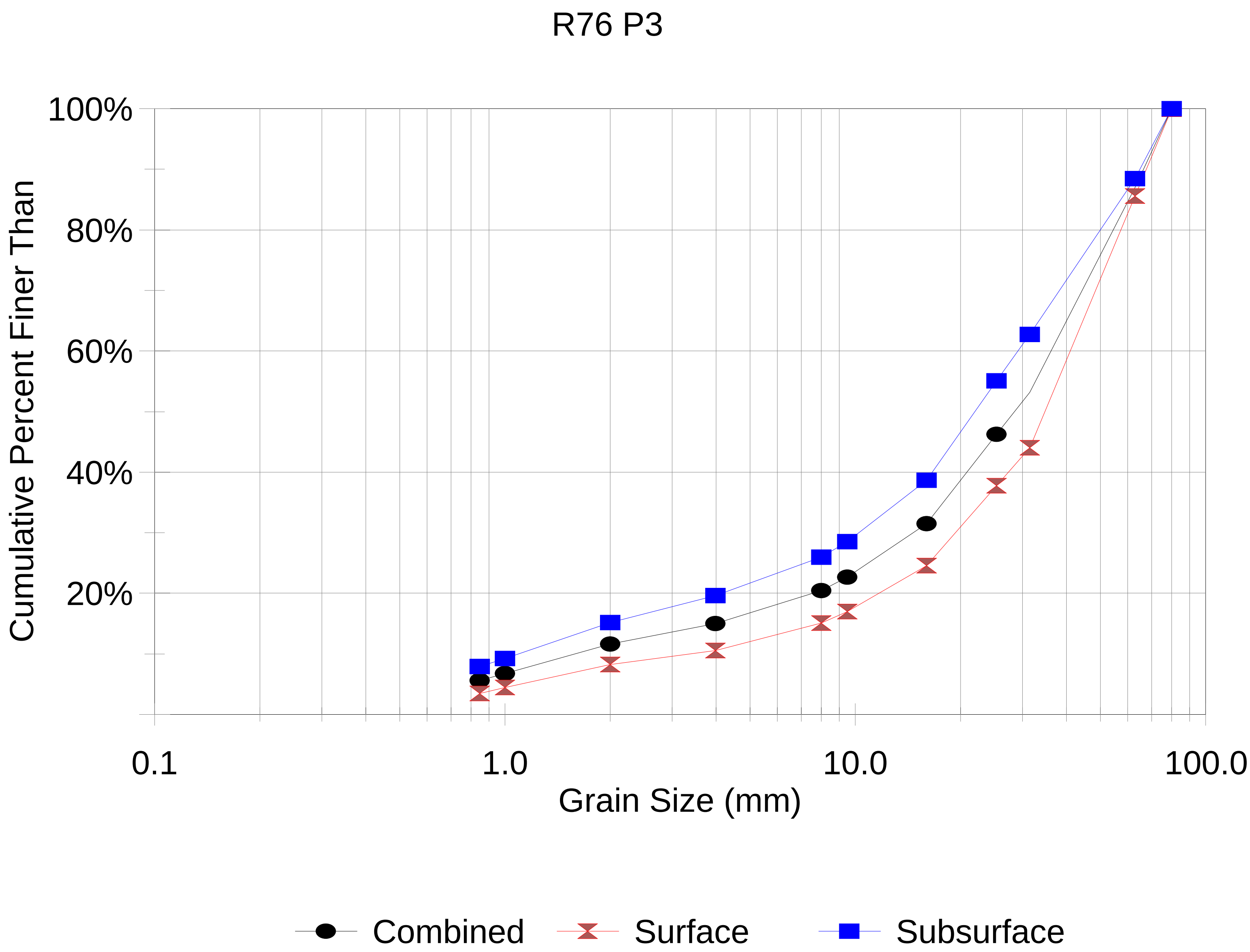

R58 P5
100%
80%
60%
40%
20%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface



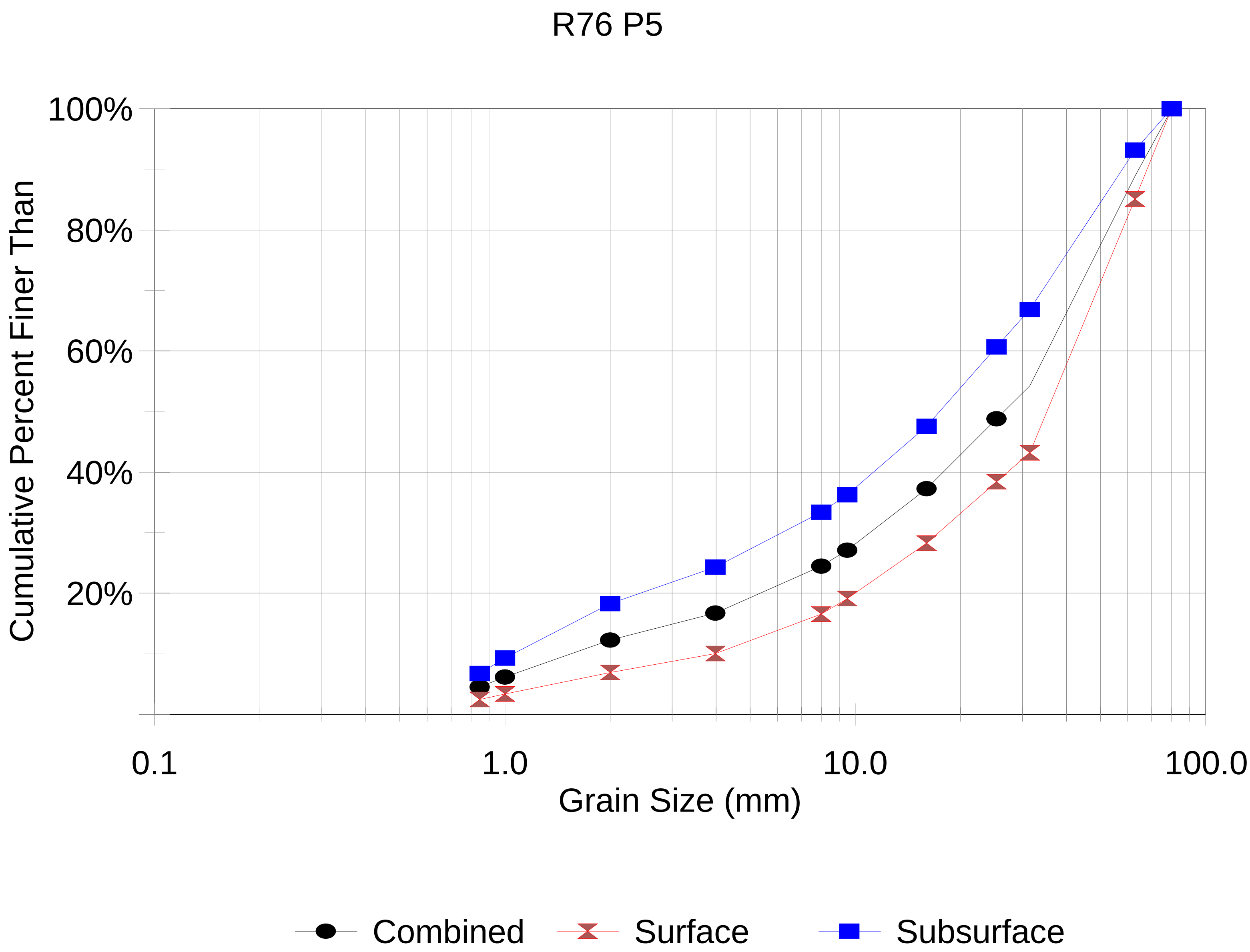
R58 P6
100%
80%
60%
40%
20%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

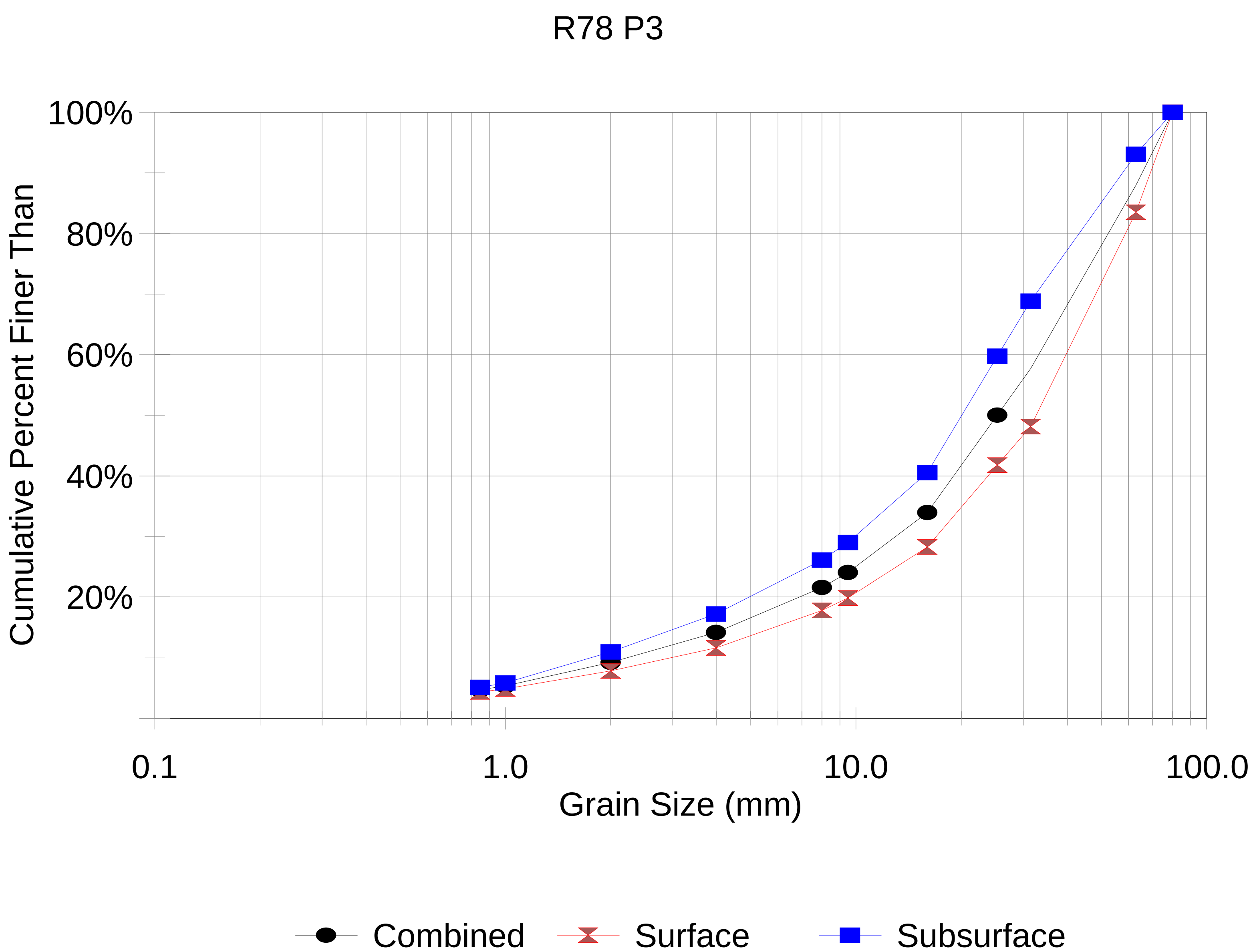

R59 P6
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface

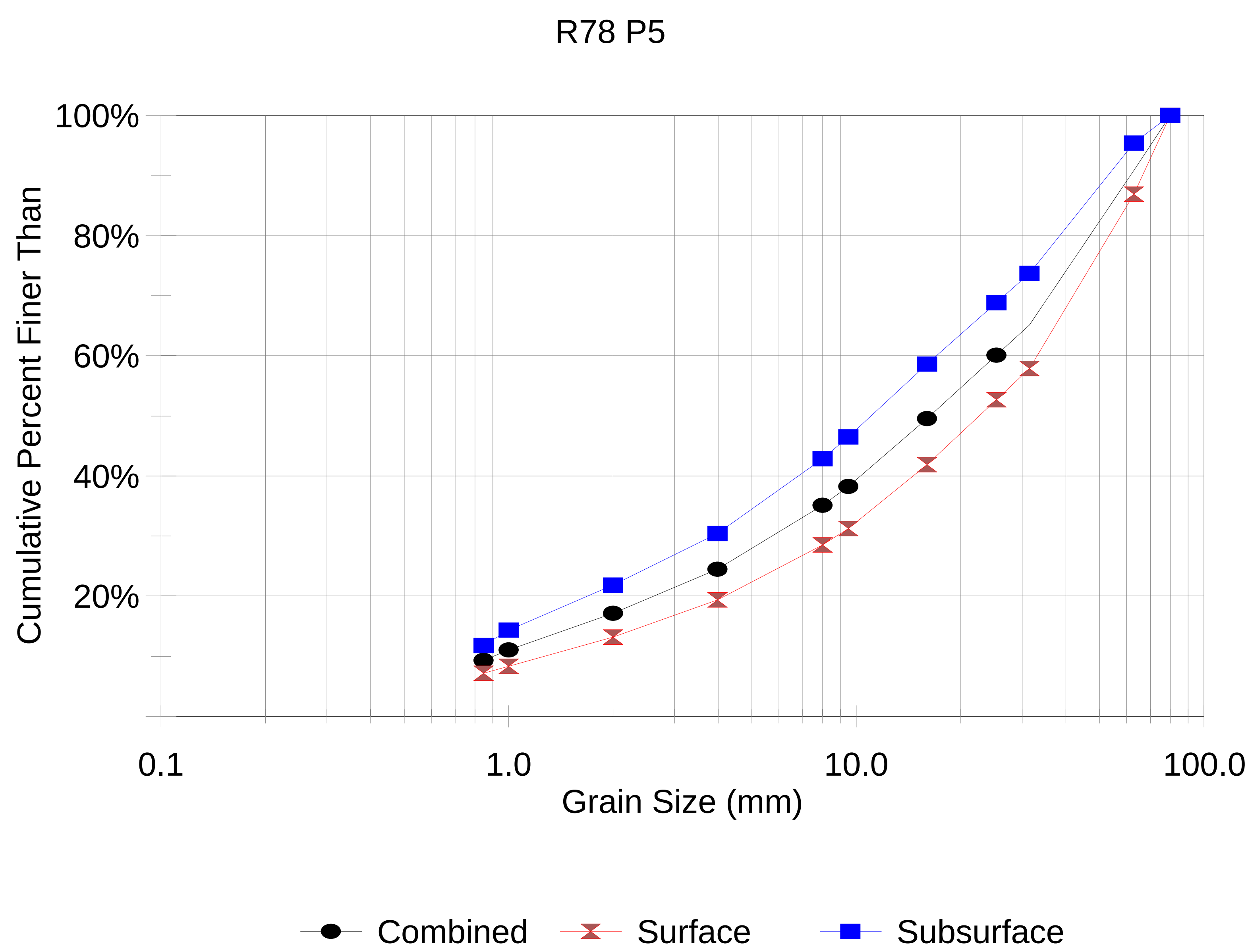

R76 P1
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface



R76 P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


R76 P5
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface


R78 P3
Cumulative Percent Finer Than
100%
80%
60%
40%
20%
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface



R78 P5
100%
80%
60%
40%
20%
Cumulative Percent Finer Than
0.1
1.0
10.0
100.0
Grain Size (mm)
Combined
Surface
Subsurface